Sustainable Basin Water Management — Challenges of Supply and Demand Management at the Basin Scale

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Preface

The papers included in these Proceedings were presented during the **USCID Eighth International Conference on Irrigation and Drainage**, held June 2-5, 2015, in Reno, Nevada. The Theme of the Conference was ***Sustainable Basin Water Management — Challenges of Supply and Demand Management at the Basin Scale***.

Increased scarcity of water supplies and competing uses and demands for water in the Western United States — and in many places around the world — will require changes to water planning and management in order to protect and effectively sustain water on the basin scale. Sustainable basin water management, a challenge even in normal hydrologic conditions with plentiful water availability, will become even more difficult for agricultural water users as the availability of supplies for irrigation continues to be threatened. As such, solutions to these challenges must include both infrastructure and management changes.

Irrigation and water district managers are making the difficult transition from solely water supply management to both supply and demand management. Basin water uses, regional governance structures, and additional jurisdictional entities have already extended involvement to irrigation and water districts, increasing their already numerous responsibilities. Being able to sustainably manage water uses and demands at the basin scale requires increased planning and management activities from all those who rely on its water.

This Conference will bring together many water resources professionals with experience and interest in governance, policy, management, financing and technical issues related to sustainable basin management, including the difficult tasks of transitioning to supply and demand management while upgrading and enhancing water infrastructure.

The authors of papers presented in these Proceedings are a mix of professionals from international, federal, state and local government agencies; water and irrigation districts; the private sector; and academia.

USCID and the Conference Co-Chairs express gratitude to the authors, session moderators and participants for their contributions.

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Conference Co-Chairs

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CALIFORNIA'S SUSTAINABLE GROUNDWATER MANAGEMENT ACT: BACKGROUND AND IMPLEMENTATION

Steve Macaulay[1]
Trevor Joseph[2]

ABSTRACT

This paper addresses groundwater management in California in the context of the 2014 Sustainable Groundwater Management Act (SGMA). The paper is in two parts, prepared by the individual authors. The SGMA consists of three separate but coordinated new state laws, together comprising state and local regulatory authority for management of groundwater.

The first part reviews historic groundwater management within California, including legal authorities and past efforts at encouraging groundwater management plans at the basin and subbasin levels. Water planning efforts prior to the adoption of the SGMA are described, putting groundwater use into the context of statewide water supply reliability as well as the importance of groundwater in serving as a drought reserve.

The second part describes SGMA, including legislative history and a description of actions they are taking to implement SGMA. The conference presentation will provide an update to the paper, since it will come at the end of the first six months of SGMA implementation. This paper addresses statutory deadlines and their importance, as well as the role of state government in supporting planning and actions at the basin and subbasin levels.

INTRODUCTION

California farmers produce a very large percentage of the fruits and vegetables for the United States, and have a very large market for exports to other countries. Agriculture in California contributes over $30 billion per year to the state's economy. This is only made possible through reliable water supplies. In addition, California's population of almost 40 million resides largely in cities that have extensive surface water and groundwater supplies. California's economy is heavily reliant on all its water resources.

Surface water rights have been governed through increasing oversight and management since the state of California was formed in 1850. Initial surface water rights were riparian, but quickly expanded to incorporate the appropriation doctrine common in other western states in the United States. Direct control by state government came about through the adoption of the Water Commission Act of 1914. The 1914 Act came about due to increasing concerns over conflicts over the apportionment of surface water rights.

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Groundwater rights have taken a separate regulatory path, governed by the courts in the case of conflict – particularly those areas in which all groundwater rights were settled by an adjudication managed by the courts. The legislative deliberations leading to the adoption of the 1914 Act considered whether the state would have permitting and management authority over groundwater extractions. Ultimately the 1914 Act limited state control to surface water rights. It took a full 100 years before the California Legislature supported any degree of state control over groundwater extractions, driven by the concerns over increasing groundwater overuse, the importance of reliable groundwater resources to the economy, and conditions of the ongoing serious drought. Governor Jerry Brown signed SGMA into law in September 2014 at the end of what was a third consecutive drought year and prior to the commencement of what is now a fourth year of drought. SGMA has the central approach of promoting local control with strong support from state government.

PRE-2015 GROUNDWATER MANAGEMENT

Historical Groundwater Use: 1900 – 1980s

Prior to the 20th century, use of groundwater was relatively minor due to a combination of available technology, relatively shallow groundwater levels in many areas, and availability of abundant surface water supplies. The advent of deep well turbine pumps in the early part of the 20th century resulted in development of many new wells, both as backup supplies during drought conditions as well as access to water supplies for lands that had inadequate surface water supplies.

In 2010, California irrigated an estimated 9 million acres of cropland using roughly 25 million acre-feet of applied water. On average, groundwater has supplied at least 30 percent of this total, and a much higher percentage when surface water supplies are reduced. Groundwater is also used extensively to meet municipal and industrial demands. In 2010 total California water use was about 43 million acre-feet, of which more than 16 million acre-feet was from groundwater.

Groundwater problems follow largely into three geographic areas: California's Central Valley, important but smaller urban and agricultural areas along the Pacific Coast, and urban and agricultural areas in southern California. The Central Valley has very extensive agricultural production, combined with major urban population centers, and contains much of California's high value agricultural production. The Sacramento Valley (northern portion of Central Valley) serves as the source of much of the state's developed surface water supplies, and has experienced only limited groundwater problems in various subregions. The San Joaquin Valley (southern portion of Central Valley) has water use greatly in excess of its native surface water supplies, and relies heavily on imported surface water and heavy use of local groundwater. As a result, there is extensive overdraft in much of the San Joaquin Valley. Figure 1 shows modeled agricultural and urban groundwater pumping in the Central Valley for the period 1922 through 2009. This graph shows an increasing trend in groundwater extractions, as well as pumping increases in dry years.

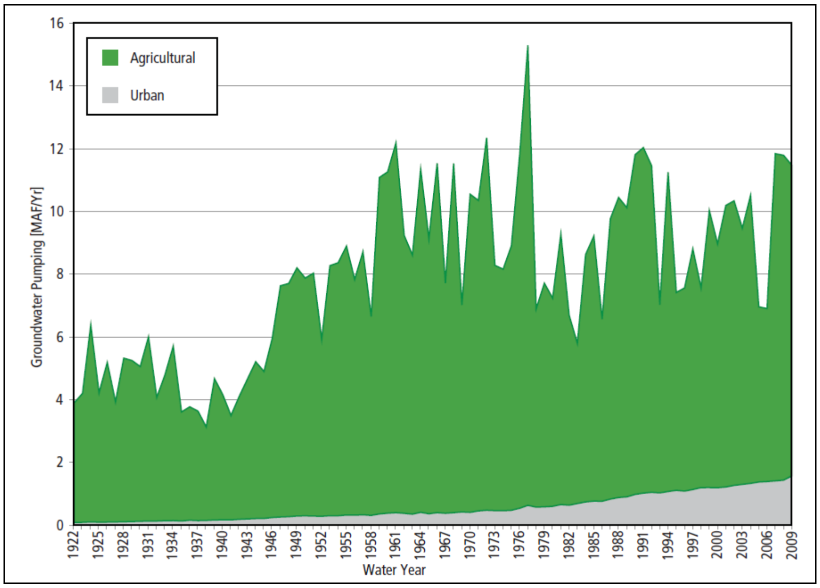

Figure 1. Simulated historical Central Valley groundwater pumping – 1922 to 2009

Figure 2 shows modeled changes in groundwater storage over the same period of time, broken down by portions of the Central Valley. There is a clear and persistent decrease in groundwater storage in most of the Central Valley, mirrored by measured water levels and signficant subsidence in several areas of the San Joaquin Valley.

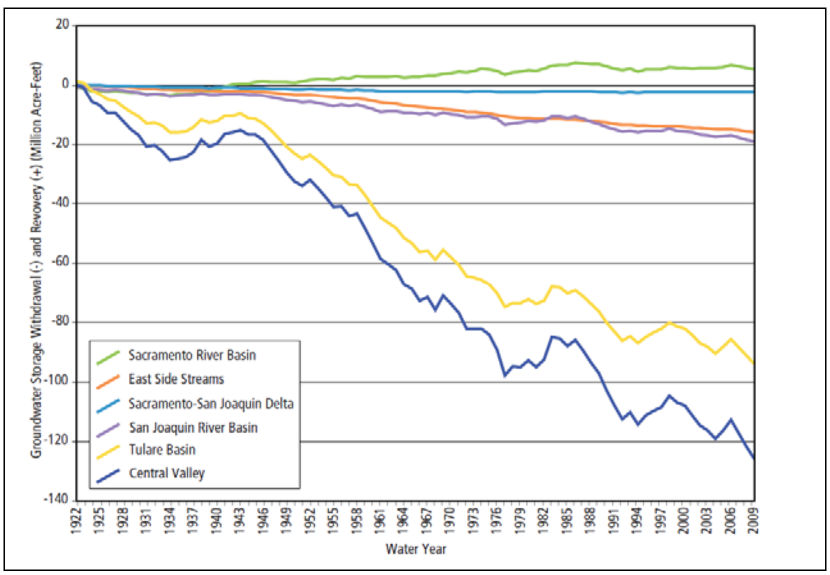

Figure 2. Simulated cumulative change in Central Valley groundwater storage – 1922 to 2009

The other major groundwater regions in California have important but relatively less severe problems as compared to the Central Valley. However, such problems are very important at the local level, particularly in those regions along the California coast that have few water supply connections to the rest of the state. Coastal groundwater basins in Santa Cruz and Monterey counties south of San Francisco are experiencing long-term seawater intrusion, and have undertaken efforts at creating freshwater salinity barriers. These areas have concerns about providing sustainable municipal water supplies for urban centers, as well as sustaining the very high value agricultural production in the Pajaro and Salinas Valleys.

A number of groundwater basins in southern California have been adjudicated, and are required by the courts to balance extraction with recharge. Some basins have significant water quality contamination brought about by industrial pollution in the 1940s and 1950s. Coastal aquifers in southern California are protected from seawater intrusion in many cases by extensive freshwater barriers.

Increased Reliance on Groundwater: 1980s – Present

Surface water reliability has decreased for more than 30 years due to increased environmental use combined with increasing regulatory restrictions. This is particularly true of exports from northern to central and southern California that go through the Sacramento-San Joaquin Delta. The conflicts between water supply reliability and protection of fish and wildlife continue, and water supply reliability continues to decline – in large measure due to documented reductions in critical fish populations and consequent application of the state and federal endangered species act.

In addition, new lands have been going into irrigation with groundwater as sole source of supply, driven by market forces. There is a large expansion – still underway – of high-value permanent crops such as almonds, walnuts and pistachios. This also comes at the same time that some lands are going out of production due to continued unreliable surface water supplies in areas of the San Joaquin Valley that do not have access to good groundwater supplies.

Brewing Crisis

According to the Public Policy Institute of California[3] the three-year period between fall 2011 and fall 2014 was the driest since recordkeeping began in 1895. To date average precipitation during water year 2015 has been significantly less than average. Drought conditions during this period have created worsening groundwater conditions throughout much of the State.

There has been only one wet year in past decade – California has experienced a series of dry and critically dry years layered on top of the trend of increasing groundwater use.

[3] Public Policy Institute of California. California's Future: Water. February 2015.

Figure 3 depicts change in groundwater levels at well locations from spring 2010 to spring 2014[4]. Basins with notable decreases in groundwater levels are in the Sacramento River, San Joaquin River, Tulare Lake, San Francisco Bay, and South Coast hydrologic regions.

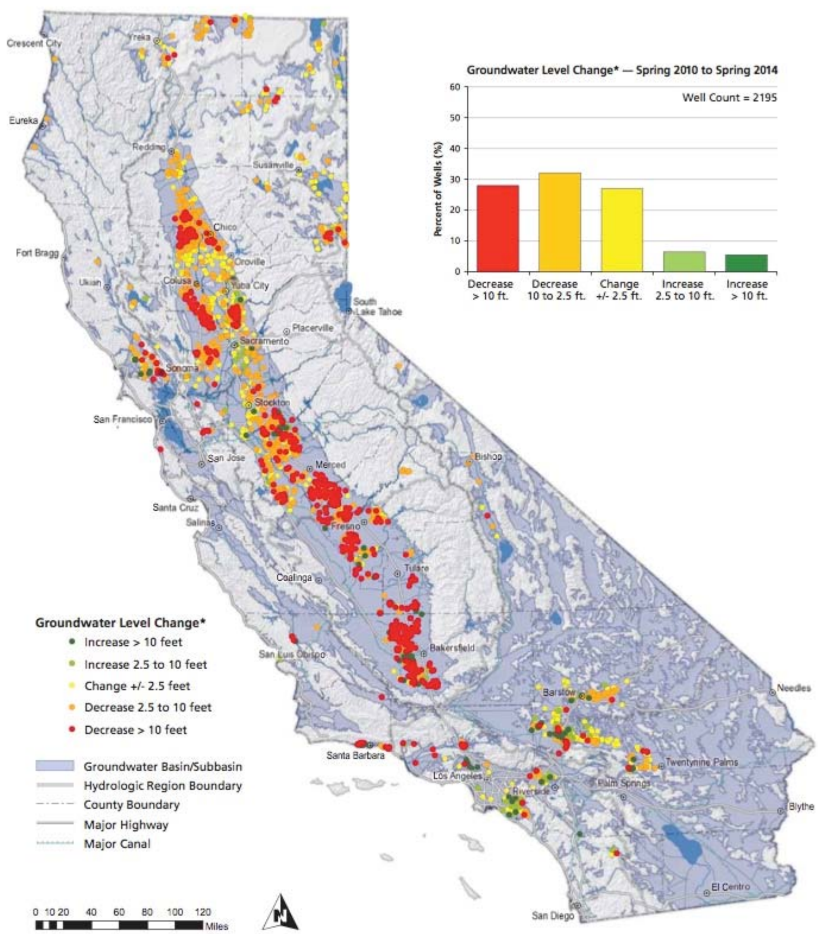

Figure 3. California Groundwater Level Changes, 2010-2014

Another method for evaluating groundwater level information is to use percentile rank. Percentile rank compares individual measurements to all available measurements for a well, and is useful in determining if a specific groundwater level measurement is statistically normal, above normal, or below normal (illustrated in the legend for Figure 4 below). It is necessary to have adequate data to generate percentile rank. For selected wells with long periods of record, the percentile rank was calculated to discern the statistical range of groundwater levels. Wells were selected based on (1) spatial distribution within the basin; (2) those that possessed a long and complete period of record; and (3) those in High and Medium priority basins.

[4] California Department of Water Resources. Public Update for Drought Response Groundwater Basins with Potential Water Shortages and Gaps in Groundwater Monitoring. April 2014.

Figure 4 depicts the percentile rank of the spring 2014 groundwater level measurements for selected wells in High and Medium priority basins[5]. Percentile rank for spring 2014 groundwater level measurements are based on the monthly median values from a given well with at least 10 years of data. The percentile rank value of the most recent measurement indicates how that measurement compares to other measurements for that well for the month studied. For example, a percentile rank of 50 matches the median water level measurement and a percentile rank of 75 indicates that the most recent measurement is higher than 75 percent of the measurements studied. Based on the available data, there are many High and Medium Priority basins that experienced spring 2014 groundwater levels that rank in the lowest 10th percentile of measurements. However, the data are not consistently available for all of the groundwater basins.

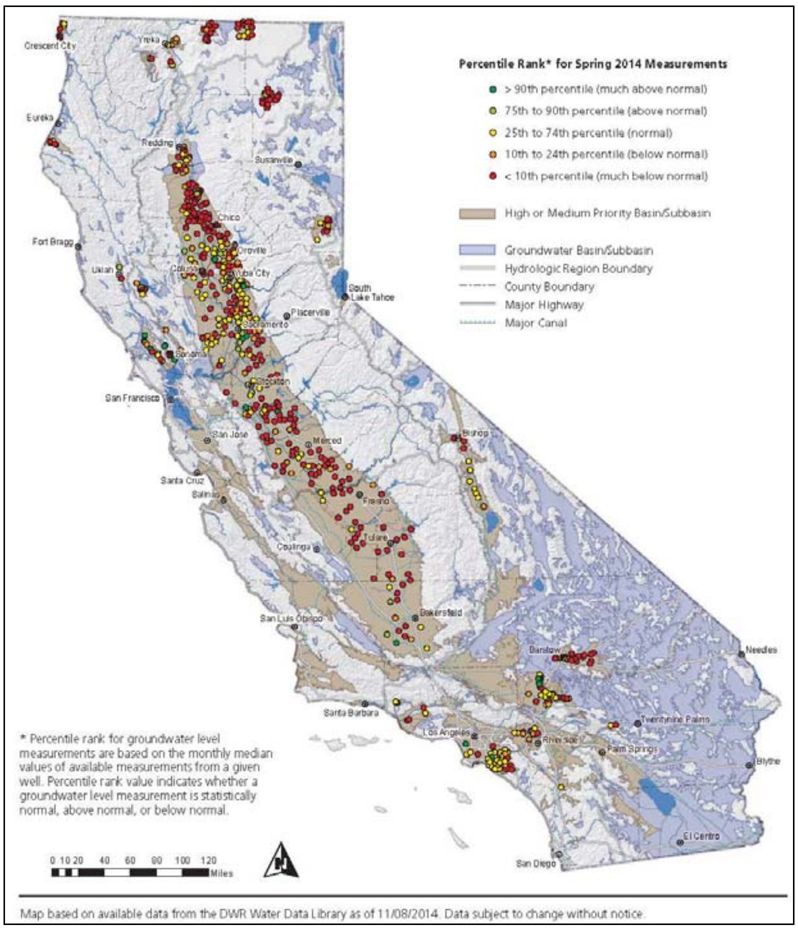

Figure 4. Percentile Rank* of Groundwater Levels in Selected Wells in High and Medium Priority Basins - Spring 2014

A popular myth is there is no groundwater management in California, as compared to other western states. In fact, California has encouraged development of groundwater

5 California Department of Water Resources. Public Update for Drought Response, Groundwater Basins with Potential Water Shortages, Gaps in Groundwater Monitoring, Monitoring of Land Subsidence, and Agricultural Land Fallowing. November 2014.

management plans for more than last decade, with financial incentives related to access to state water bond funds. However, such plans largely have lacked the proper mix of legal and institutional authorities needed to adequately manage groundwater in a comprehensive way. So while there are a number of groundwater management success stories in various subbasins throughout the state, on the whole groundwater management at the end of 2014 was at a crossroads – particularly given the increased reliance on groundwater during the continuing prolonged drought, and long-term statewide overdraft of more than 2 million acre-feet.

IMPLEMENTING THE 2014 GROUNDWATER MANAGEMENT ACT

SGMA Description

On September 16, 2014, Governor Jerry Brown signed into law a three-bill legislative package: AB 1739 (Dickinson), SB 1168 (Pavley), and SB 1319 (Pavley). These laws are collectively known as the Sustainable Groundwater Management Act. This new legislation defines ***sustainable groundwater management*** as the "management and use of groundwater in a manner that can be maintained during the planning and implementation horizon without causing undesirable results" {California Water Code § 10721(u)}. "***Undesirable results***" are defined in the legislation as any of the following effects caused by groundwater conditions occurring throughout the basin {California Water Code § 10721(w) (1-6)}:

- Chronic lowering of groundwater levels indicating a significant and unreasonable depletion of supply
- Significant and unreasonable reduction of groundwater storage
- Significant and unreasonable seawater intrusion
- Significant and unreasonable degraded water quality
- Significant and unreasonable land subsidence
- Surface water depletions that have significant and unreasonable adverse impacts on beneficial uses of the surface water.

The legislation requires High and Medium Priority basins under the CASGEM program subject to ***critical conditions of overdraft*** to be managed under a groundwater sustainability plan by January 31, 2020 {California Water Code § 10720.7(a) (1)}, and requires all other groundwater basins designated as High or Medium Priority basins to be managed under a groundwater sustainability plan by January 31, 2022 {California Water Code § 10720.7 (a) (2)}. The legislation provides for financial and enforcement tools to carry out effective local sustainable groundwater management through formation of ***Groundwater Sustainability Agencies (GSAs)***. The SGMA does not require adjudicated basins to develop GSPs, but they are required to report their water use. Additional work is underway to examine methods for expediting the adjudication process.

The legislation significantly increases the role and responsibilities of DWR to support sustainable groundwater management. The legislation directs DWR to:

- Complete regulations for changing basin boundaries and establish content for and review of Groundwater Sustainability Plans (GSPs)
- Update basin priorities

• Conduct groundwater assessments into the next decade.

Together these new responsibilities require DWR to manage its existing resources and expand its expertise to meet the challenges and opportunities ahead.

The new legislation also expands the role of DWR to support local implementation of sustainable groundwater management, and allows for State intervention (State Water Resources Control Board {SWRCB}) at discrete points throughout the process if local agencies are not willing or able to manage groundwater sustainably. Figure 5 summarizes the major timelines and milestones on California's path to sustainable groundwater management. Improving California groundwater management practices will require that local and regional agencies have the incentives, tools, authority, and guidance to develop, implement, and enforce sustainable groundwater management practices to provide the benefits of water supply reliability and resiliency, public health and safety, ecosystem services, and a stable California economy.

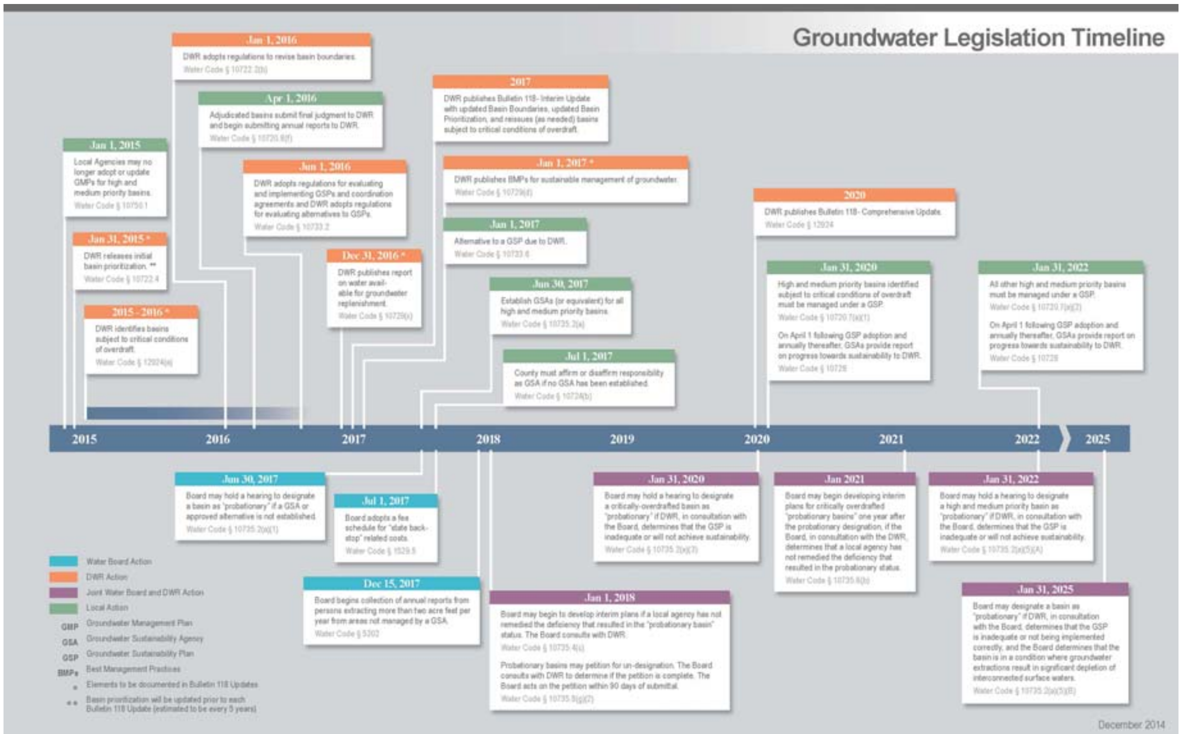

Figure 5. Major Timeline of Key SGMA Milestones

Implementation Components

DWR's goals and objectives are aimed at achieving the overall goal of sustainable groundwater management -- assisting local agencies to achieve balanced groundwater basin conditions and avoid adverse impacts such as land subsidence and long-term overdraft of the basin. Two key principles of the legislation guiding DWR are:

- Groundwater is best managed at the local or regional level, and local agencies should have the tools they need to sustainably manage their resources. Some local and regional agencies do not currently have the necessary tools and resources to be successful. The legislation ensures that local and regional agencies will have the resources they need to sustainably manage groundwater, including the necessary authority, technical information, and financial resources.

- When local or regional agencies cannot or will not manage their groundwater sustainably, the State will intervene until the local agencies develop and implement sustainable groundwater management plans. This limited State intervention would be temporary–until an adequate local program is established–to ensure the protection of the groundwater basin and its users from overdraft, subsidence, and other problems stemming from unsustainable uses of groundwater resources.

<u>DWR's Groundwater Sustainability Goal</u>. DWR will seek to assist local and regional GSAs to manage groundwater sustainably for long-term reliability, for economic, social, and environmental benefits, for current and future beneficial uses, and as an integral part of broader sustainable water management throughout California. To achieve this goal, DWR has developed five objectives to organizing and executing the work necessary for successful program implementation.

Objective 1: Develop a Framework for Sustainable Groundwater Management -- Provide a structure that will enable GSAs to achieve success will require many factors be addressed. This objective will address basin boundaries and prioritization, GSP formulation and content, best management practices and water budgeting. In order to address directives from the SGMA, DWR will develop regulations to inform and support regional efforts.

Objective 2: Provide Statewide Technical Assistance to Groundwater Sustainability Agencies -- Provide technical assistance to GSAs will be crucial in enabling their success in managing their groundwater basins. GSAs will depend on easily accessible data and will be able to access this information via an online information system. Well standards and water conservation assistance will also be addressed.

Objective 3: Provide Statewide Planning Assistance to Support Groundwater Sustainability -- DWR's periodic groundwater report (Bulletin 118) provides a systematic evaluation of groundwater basins in California, and will be updated to reflect critical information including basin boundaries, groundwater quality data, yield data, and water budgets. This information will support and inform statewide water planning and assessment, including water budgeting, via DWR's California Water Plan (DWR Bulletin 160). DWR will also provide information to support local groundwater recharge projects.

Objective 4: Assist State and GSA Alignment and Provide Financial Assistance -- Strong alignment and collaboration between and amongst local, regional, and State agencies will be critical to achieving sustainable groundwater management statewide. DWR will provide venues for communication and engagement, educational materials, and facilitation services, as well as financial assistance to help ensure success.

Objective 5: Provide Interregional Assistance -- Achieving this objective will require DWR to support regional water managers with information on water reliability, storage and conveyance opportunities, water available for replenishment, and updated surface groundwater interactions. These objectives will be addressed by way of a suite of actions undertaken by DWR over the coming years to promote and support sustainable water management.

Implementation Challenges

The SGMA provides a framework for best management of groundwater resources. There will be many challenges to overcome in implementing the SGMA, but addressing these will foster successful sustainable groundwater management. It is critical to identify and understand those challenges as DWR works with State, federal, and local agencies, tribes, and other stakeholders to achieve groundwater sustainability goals. Success will depend upon the following factors:

- **Balanced water supply and demand**: Current available surface water and safe yield of the groundwater basins must be balanced to support the current and future land use in the basin.
- **Coordinated water management within a basin**: Moving from disjointed basin management with sometimes conflicting interests and inconsistent objectives to a more coordinated structure will enable sustainable water management within basins.
- **Regulatory oversight and enforcement**: Managing groundwater extraction, establishing a fair allocation of groundwater resources, coordinating land use changes versus resource management, and controlling future groundwater development.
- **Regulation and criteria development**: DWR has the opportunity to promote local/regional groundwater management flexibility while ensuring that the ultimate goal of statewide sustainable groundwater management is achieved by developing appropriate and supportable criteria and regulations.
- **Basin stabilization**: Full recovery of the groundwater system may be possible in some basins. Critical issues that will need to be addressed include land subsidence and salts and nutrient concentrations. By addressing these impacts and challenges, basin managers can achieve significant improvements.
- **Improved data management**: Accurate and abundant data is necessary to assist basins in adequately developing and implementing plans to achieve the goals of the SGMA. This could include a more strategic and focused system of groundwater monitoring networks, extraction reporting, model and tool development, and a standardized process to determine water budgets for the basin.
- **Funding and resources**: Immediate, reliable, and long-term State and local funding will enable and support the achievement of the goals for sustainable groundwater management. Certain rural and disadvantaged communities will benefit from funding to help achieve their goals.
- **Communication and outreach**: Fostering robust communication amongst multiple entities with differing roles and responsibilities and stakeholders with differing and sometimes conflicting interests will further chances for success. Flexibility and cooperation will support consensus building amongst the various interested groups.

• **Uncertainties**: Addressing uncertainties directly will improve the likelihood for success, including those related to data, modeling and the long term effects of climate change. However, DWR will not be able to completely eliminate uncertainties and will need to allow for adaptive management of systems as knowledge improves.

Phased Implementation

It will take years to achieve the ultimate goal of local sustainable groundwater management at a statewide scale. DWR, SWRCB, and other State agencies will work together to implement actions required by law, and assist local agencies in achieving groundwater sustainability. Figure 6 provides and overview of the phased implementation of DWR's groundwater sustainability actions.

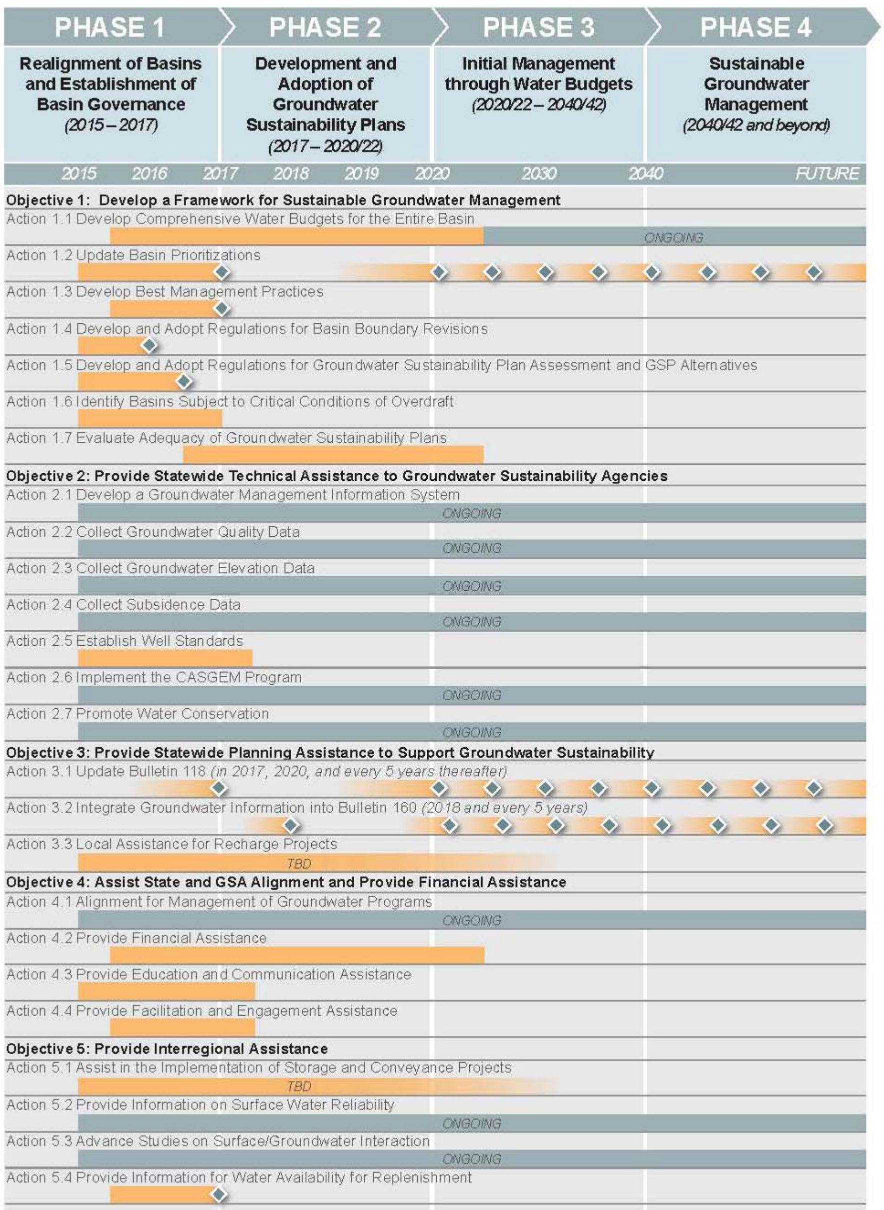

Figure 6. Phased Implementation of DWR Groundwater Sustainability Actions

CONCLUSIONS

California faced a growing groundwater management crisis in late 2014 – a culmination of long-term groundwater management challenges aggravated by declining surface water reliability over more than 3 decades and the continuing challenges of the current prolonged drought. The California Legislature and Governor responded in part through adoption of a fundamental change in California water law. The 2014 Sustainable Groundwater Management Act requires active management of groundwater in medium and high priority basins throughout the state. The new law continues the historic approach of local leadership with regard to groundwater management, but adds regulatory control to local agency authorities with the state in a supportive role and serving as the regulatory backstop.

The new law went into effect in January 2015, and implementation is moving forward on an aggressive schedule. The California Department of Water Resources is fully engaged in supporting local agencies and is in the process of developing regulations to guide their efforts. Up-to-date information on SGMA implementation can be found at DWR's groundwater web site, http://www.water.ca.gov/groundwater/.

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STATE STRATEGIES FOR SUSTAINABLE GROUNDWATER MANAGEMENT AND CALIFORNIA'S NEW ACT

Sarah R. Liljefelt[1]
Kevin J. Johnston[2]

ABSTRACT

Until 2015, no comprehensive, statewide regulatory scheme governed the extraction or use of percolating groundwater in California. Percolating groundwater is groundwater not within subterranean streams flowing through known and definite channels, generally defined by the following characteristics: 1) subsurface channel; 2) impermeable bed and banks; 3) channel course is known or capable of being determined by reasonable inference; and 4) groundwater flows in the channel. Percolating groundwater is all other groundwater, such as that held in undefined alluvial aquifers.

In many western states, percolating groundwater is managed in the same regulatory framework as other groundwater, and is even sometimes considered alongside surface water uses due to hydraulic connections between water sources. In most areas of California, however, landowners overlying percolating groundwater may pump without authorization from the State that issues permits and regulates water use for surface and "subterranean stream" water uses.

The California Sustainable Groundwater Management Act was signed into law on September 16, 2014, and went into effect at the beginning of 2015. The Act requires the Department of Water Resources to prioritize groundwater basins. Groundwater sustainability agencies will facilitate data reporting and will promulgate sustainability management plans in medium and high priority basins, as well as having the power to carry out the plans, including, if necessary, acquiring land and water.
The Act is a step in the right direction for California, but it is not without its flaws. In order to manage groundwater for long term sustainability California will need to continue to improve and refine its laws and look toward other states' strategies for guidance, especially concerning percolating groundwater and surface water connections.

INTRODUCTION

The Sustainable Groundwater Management Act fundamentally changes the way groundwater is regulated in California. California has finally joined most other Western states in recognizing the need for comprehensive statewide groundwater planning, management, and regulation. California has never in its history had such a program, even

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as other states have for decades. It took a combination of an unprecedented three year drought, widespread groundwater over-drafting, subsidence and collapse of groundwater basins around the state and subsequent contamination to finally convince California's political leaders that the State's failure to manage its groundwater resources had to change.

This paper summarizes the basic provisions of the Act, identifies some of the Act's critiques, and discusses some of the tools used in other western states to sustainably manage groundwater resources, as well as in conjunction with hydrologically connected surface water sources.

CALIFORNIA PRE-ACT SYSTEM OF GROUNDWATER USE

In California, groundwater is classified as either percolating groundwater or as a subterranean stream. Groundwater not flowing as a subterranean stream is classified as percolating groundwater. When the flow of ground water is confined to a known and defined subsurface channel it is a subterranean stream.[3]

In most areas of California, overlying land owners may extract percolating groundwater and put it to beneficial use without approval from the State Board or a court.[4] Until 2015, California did not have a permit process for regulation of percolating groundwater use. "Reasonable use" has been the guiding doctrine and limitation on the use of percolating groundwater.[5] The use of groundwater outside the basin is subordinate to use on overlying lands.[6]

Additionally, in several basins groundwater has been regulated in accordance with court decrees adjudicating the ground water rights within the basins.[7] Many counties also regulate the use of groundwater for quality and quantity, and require permits to export groundwater from the county.[8]

THE NEW GROUNDWATER LEGISLATION

On August 29, 2014, the California Legislature passed legislation aimed at comprehensively regulating groundwater in California known as the Sustainable Groundwater Management Act ("Act").[9] Governor Brown signed the legislation on

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[3] Cal. Water Code § 1200.
[4] Cal. Water Code §§ 1200, 2500.
[5] Katz v. Walkinshaw, 141 Cal. 116, 120, 74 P. 766 (1903).
[6] *Id*.; California Envtl. Prot. Agency, *The Water Rights Process*, http://www.waterboards.ca.gov/waterrights/board_info/water_rights_process.shtml (last visited Mar. 3, 2015).
[7] Gregory S. Weber, *Forging A More Coherent Groundwater Policy in California: State and Federal Constitutional Law Challenges to Local Groundwater Export Restrictions*, **34 SANTA CLARA L. REV. 373, 375** (1994).
[8] *See, e.g.*, Lassen County Code Title 17.
[9] *Sustainable Groundwater Management Act (SGMA)*, A.B. 1739, S.B. 1168, S.B. 1319, 2013-2014 Leg. Sess. (Ca. 2014).

September 16, 2014, making the Act effective January 1, 2015. The Act is codified in California Water Code § 10720 *et seq.*, and is organized in Part 2.74 of Division 6 titled *Sustainable Groundwater Management.*

The Act is intended to provide for local management of groundwater basins. There are 515 alluvial groundwater basins and subbasins in California.[10] The Act requires the Department to prioritize the basins as high-priority, medium-priority, low-priority, or very low-priority using the California Statewide Groundwater Elevation Monitoring ("CASGEM") system by January 31, 2015.[11] The Act does not require compliance with the Act from basins defined as low and very low-priority; however, high and medium-priority basins must meet deadlines established by the Act to maintain local control of such basins.[12] If a basin fails to timely meet the statutory deadlines, the Act authorizes the State Water Resources Control Board ("Board") to control groundwater management in that basin.[13]

The Act states it will not alter, establish or determine groundwater or surface water rights, but rather govern how those rights are exercised.[14] The Act also gives state government significant authority in monitoring the extraction of groundwater and imposition of fees.[15]

<u>Basics</u>

Sustainability plans can vary from simple basin-wide plans developed and implemented by individual local agencies, to multiple plans by different local agencies operating in the same basin, to state-imposed plans where no sufficient local plan exists.[16] While sustainability plans must contain a number of specific requirements,[17] by far the most significant is that they be designed to meet the Act's "sustainability goal" within 20 years of implementation.[18] The sustainability goal is, in a nutshell, a stated objective to "achieve sustainable groundwater management" by ensuring that a given basin is "operated within its sustainable yield," or in other words, that the basin is operated in such a way as not to cause "undesirable results."[19] Many of these standards leave a great

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[10] State of California, *Bulletin* 118, http://www.water.ca.gov/groundwater/bulletin118.cfm (last visited Dec. 5, 2014).
[11] Cal. Water Code § 10722.4. The CASGEM Groundwater Basin Prioritization is a statewide ranking of groundwater basin importance that incorporates groundwater reliance and focuses on basins producing greater than 90% of California's annual groundwater. The California Water Code requires a statewide prioritization of California's groundwater basins using the following eight criteria: Overlying population; Projected growth of overlying population; Public supply wells; Total wells; Overlying irrigated acreage; Reliance on groundwater as the primary source of water; Impacts on the groundwater; including overdraft, subsidence, saline intrusion, and other water quality degradation; and Any other information determined to be relevant by the Department. Cal. Water Code § 10933.
[12] Cal. Water Code § 10720.7.
[13] Cal. Water Code § 10735.2.
[14] Cal. Water Code § 10720(b).
[15] Cal. Water Code §§ 10726.4, 10730, 10730.2, 10730.4.
[16] See Cal. Water Code § 10727(b).
[17] See id. §§ 10727.2-10727.6.
[18] See id. § 10727(a), (b).
[19] *Id*. § 10721. The Act lists the following as potential undesirable results in this context: (1) chronic lowering of groundwater levels indicating a significant and unreasonable depletion of supply if continued

deal of interpretive work to regulatory agencies, and ultimately to the courts. Disputes over the practical meaning of key terms such as "sustainable groundwater management," "sustainable yield," and "undesirable results," for example, will likely lead to litigation as time progresses.

The Act also contains procedural requirements for plan development and implementation, and exempts many activities involved in that process from the environmental review requirements of the California Environmental Quality Act ("CEQA").[20]

While the Act will regulate California's groundwater on a statewide basis for the first time, it does not cover every groundwater basin within the state's jurisdiction, nor will its impacts be felt immediately. [21] The statute generally does not apply to specified basins that have already been adjudicated under existing law,[22] for example, and it does not require sustainability plans from basins considered to be low priority.[23] Moreover, sustainability plans need not be implemented for several years, and affected basins are not required to attain sustainability goals until approximately 2040.

That said, the California Department of Water resources ("DWR") has estimated that the Act will cover 96% of groundwater used in California.[24] California water users cannot afford to wait to get involved in efforts now underway to shape the manner in which the statute is applied.

<u>The Focus of Local Control</u>

In enacting the Act, the California legislature sought to "manage groundwater basins through the actions of local governmental agencies to the greatest extent feasible."[25] For the most part, any local agency with water supply, water management or land use responsibilities in a given groundwater basin (or a combination of such agencies) can become the groundwater sustainability agency for that basin.[26]

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over the planning and implementation horizon; (2) significant and unreasonable reduction of groundwater storage: (3) significant and unreasonable seawater intrusion; (4) significant and unreasonable degraded water quality, including the migration of contaminant plumes that impair water supplies; (5) significant and unreasonable land subsidence that substantially interferes with surface land uses; and (6) depletions of interconnected surface water that have significant and unreasonable adverse impacts on beneficial uses of the surface water.

[20] CEQA does not apply to the preparation and adoption of plans pursuant to the Act, but it does not exempt actions taken pursuant to a plan adopted pursuant to the Act from CEQA. Cal. Water Code 10728.6.

[21] Cal. Water Code § 10720.3.

[22] *Id.* § 10720.8. The Act does, however, require the water master or local agency for each adjudicated area to submit certain documents relating to the adjudication, as well as annual reports containing information relating to water use in the basin "to the extent available." Id.

[23] Id. § 10720.7.

[24] *See* http://www.water.ca.gov/groundwater/sgm/SGM_BasinPriority.cfm.

[25] Cal. Water Code § 10720.1(h).

[26] *See Id*. § 10723(a), 10721(m). The SGMA also lists several local agencies as the presumptive exclusive sustainability agencies for their respective basins. *Id*. § 10723(c).

The Act gives sustainability agencies a number of powers and authorities in addition to those they already may possess. Agencies are authorized, among other things, to conduct investigations; require registration of facilities that extract groundwater; require said facilities to measure the amount of water they extract; acquire property including water rights; regulate, limit or allocate groundwater extraction; and authorize transfers of groundwater allocations.[27] They also have the power to "impose fees, including . . . permit fees and fees on groundwater extraction" to support their activities, and to bring enforcement actions seeking civil penalties for violations relating to rules implemented pursuant to the Act.[28]

The Act's use of local planning and management – as opposed to purely centralized state control – should be viewed as valuable opportunities for informed and proactive water users to have a say in groundwater sustainability planning from the start.

However, a defect in the new groundwater legislation is that for most areas of the state there is no requirement that local groundwater sustainability agencies require basin pumpers to actually report the amount of water they're extracting from a particular basin in a given year. There are some exceptions in the new law and while individual agencies have the *option* to require such reporting as part of their groundwater sustainability plans, political opposition from groundwater extractors to such reporting requirements makes it doubtful that the agencies will actually do so.[29] Nor do state water officials have the ability to require groundwater extraction reporting data on any sort of comprehensive basis.[30]

State Oversight and Intervention

While the Act generally emphasizes local management of groundwater resources, it does provide for State involvement. For example, DWR must develop and publish best management practices for sustainable groundwater management, and it is responsible for reviewing sustainability plans every five years to ensure compliance with the Act.[31] In addition, the Board can "designate a basin as a probationary basin" for failure to develop a groundwater sustainability plan where one is needed, or for implementation of an insufficient plan.[32] If a local agency fails to remedy the problem that led to a designation, the Board may adopt its own interim sustainability plan for the basin.[33]

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[27] *Id.* §§ 10725.4 – 10726.4.
[28] *Id.* §§ 10730(a), 10730.2, 10732.
[29] Cal. Water Code § 10727.2.
[30] *Id.* § 10735.8.
[31] *Id.* §§ 10733, 10733.8.
[32] *Id.* § 10735.2.
[33] *Id.* § 10735.8. Section 10735.8(b)(1) grants the SWRCB the authority to impose an interim plan on basins where groundwater extractions result in "significant depletions of interconnected surface waters." This language seems to be limited to those situations where there is a direct and substantial relationship between surface waters and groundwater and would reasonably be the groundwater equivalent of a "subterranean stream flowing through a known and definite channel." However, the question of what constitutes a "significant depletion" is likely to prove controversial. If the SWRCB were to take the position that any groundwater extraction that causes or contributes to a stream reach being a "losing reach" (i.e., a reach where water in the stream percolates into the ground), then it would effectively assert control over all uses of water in the area. On the other hand, if the SWRCB were to follow the historic case law on

DWR is also tasked with establishing the initial priority for the State's groundwater basins, a job of considerable consequence given that many of the Act's requirements apply only to those basins designated as high or medium priority.[34] As explained above, DWR announced that basin designations under the California Statewide Groundwater Elevation Monitoring program will serve as the initial prioritization required by the Act.[35]

Important Dates

The following are some of the more important deadlines for future actions to implement the Act. DWR must adopt regulations for evaluating sustainability plans, implementation of sustainability plans, and plan alternatives by June 1, 2016. DWR must publish a report with its best estimate of water available for groundwater replenishment throughout the state by December 31, 2016. DWR must publish best management practices for sustainable groundwater management by January 1, 2017.

Agencies wishing to submit alternatives to groundwater sustainability plans must do so by January 1, 2017. The State Board can designate basins as probationary if no local agency has elected to be a groundwater sustainability agency and intends to develop a sustainability plan or has submitted an alternative by June 30, 2017. If, after July 1, 2017, a groundwater sustainability agency or county has not assumed responsibility for a groundwater basin, many water users will be subject to mandatory extraction reporting. By January 31, 2020 high- and medium-priority basins subject to "critical conditions of overdraft" must be managed under a groundwater sustainability plan or plans. By January 31, 2022, all other high- and medium-priority basins must be managed under a groundwater sustainability plan or plans.

EXAMPLES OF GROUNDWATER MANAGEMENT IN OTHER WESTERN STATES

In the arid western states, the Prior Appropriation system of "first in time, first in right" governs most surface water use.[36] Most western states have similarly enacted a prior appropriation system for the use of groundwater, but some states have not followed that trend, such as California's lack of regulation for percolating groundwater.[37]

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interconnected streams, it would only develop interim plans in the most obvious cases of excessive groundwater extractions, thereby applying only a light touch. The challenge for the SWRCB and its staff will be to not pull out the regulatory hammer before all other avenues have been exhausted.

[34] *Id.* § 10720.7.

[35] *See* http://www.water.ca.gov/groundwater/Sustainable_GW_Management/SGM_BasinPriority.cfm. A list of these basin designations can be found at http://www.water.ca.gov/groundwater/casgem/pdfs/lists/StatewidePriority_Abridged_05262014.pdf.

[36] Some states still recognize riparian use rights, which is the system used in the eastern United States where landowners adjacent to surface water sources may use the water, but non-riparian landowners may not. For example, California recognizes both riparian and prior appropriative rights, but Oregon only recognizes riparian rights established before the Oregon Water Code was enacted. Or. Rev. Stat. § 539.010.

[37] Prior to the 1935 amendments to the Utah Water Code, Utah law stated: "The water of all streams and other sources in this State, whether flowing above or under the ground, *in known or defined channels*, is hereby declared to be the property of the public, subject to all existing rights to the use thereof." Utah Rev. Stat. 1933, sec 100-1-1 (emphasis added). Thus, Utah's water code was similar to California's water code

Percolating groundwater is water in the alluvial, unconfined zone. The lack of regulation of all groundwater, and percolating groundwater to a more immediate degree, can affect surface water availability, as all water is connected. The lack of regulation of percolating groundwater can have more noticeable effects on surface water sources because such water oftentimes contributes to surface streams, or can pull water from surface streams if pumped by water users. Lack of regulation also puts great strain on water users using the same source of water, as there is no mechanism to resolve disputes between percolating groundwater users.

California is a little "late to the party" of statewide regulation for sustainability of groundwater resources. A summary of groundwater regulation tools utilized by other western states is informative for understanding how western states tackle the issue of sustainable groundwater management, and the interconnection with surface water resources. Select groundwater management strategies in other western states are discussed below.

Oregon

Oregon is a prior appropriation state.[38] With limited exceptions, surface waters and all underground waters are managed in the same permitting system, where water users must obtain a water use permit before using surface water or groundwater.[39] The Oregon Water Resources Department ("OWRD") conducts availability analysis for all new water use applications,[40] and the issuance of new permits is limited in designated "limited" or "critical" groundwater areas.[41]

When considering whether to issue a new groundwater permit, OWRD utilizes conjunctive use management with surface water if the source of groundwater is deemed, or even presumed, to be connected to surface water sources. A permit for the appropriation of groundwater will not be issued if the appropriation might "impair or substantially interfere with existing rights to appropriate surface water by others."[42] OWRD's rules state that all wells located less than a quarter mile from surface waters, and withdraw groundwater from unconfined aquifers, are presumed to be hydraulically connected to surface water sources.[43] Aquifers determined to be hydraulically connected

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in that it excluded percolating water from State control. However, Utah's water code was amended to read, "all waters in this state, whether above or under the ground are hereby declared to be the property of the public, subject to all existing rights to the use thereof."

[38] Or. Rev. Stat. §§ 537.120, 537.130.

[39] Waters and Water Rights § I(C)(5) (Robert E. Beck ed., 3rd Edition).

[40] Or. Rev. Stat. § 537.620(4).

[41] Prior to the 1935 amendments to the Utah Water Code, Utah law stated: "The water of all streams and other sources in this State, whether flowing above or under the ground, *in known or defined channels*, is hereby declared to be the property of the public, subject to all existing rights to the use thereof." Utah Rev. Stat. 1933, sec 100-1-1 (emphasis added). Thus, Utah's water code was similar to California's water code in that it excluded percolating water from State control. However, Utah's water code was amended to read, "all waters in this state, whether above or under the ground are hereby declared to be the property of the public, subject to all existing rights to the use thereof."

[42] Or. Rev. Stat. § 537.629.

[43] Or. Admin. R. § 690-009-0040(2). This is a rebuttable presumption. *Id.*

to surface sources are "assumed to have the potential to cause substantial interference with the surface water source" under certain listed circumstances.[44]

This rebuttable presumption errs on the side of caution, protecting surface water uses, and requiring that persons desiring to use groundwater prove their new use will not interfere with existing surface water use rights. In practice, it is nearly impossible for an applicant to prove no interference in an alluvial aquifer within a mile of a surface water source, and so new permits are generally denied unless surface water is available for appropriation.

Oregon's Scenic Waterway Act also prohibits groundwater appropriations that may result in diminished surface water flows in designated rivers or tributaries.[45] To establish that a groundwater use will decrease surface flows, the OWRD Director must find that a hydraulic connection exists based upon a "preponderance of the evidence,"[46] meaning that a connection is more likely than not. OWRD's decision need only be based on "relevant and available field information,"[47] and so OWRD may not investigate the specific location at issue, and may instead use general reports about the area or nearby wells. Thus, again the burden may be placed on the person desiring to use groundwater to overcome the presumption of interference.

Colorado

Colorado has adopted the prior appropriation doctrine.[48] As is the case with most western states that have adopted a Conjunctive Management approach, the applicability of Colorado's conjunctive management system turns on whether the two water sources are hydrologically connected. Other than "designated" waters (which are managed differently) groundwater that is connected to surface water is defined as "tributary" water.[49] Pumping water from these so called tributary aquifers has been found to have an effect on surface waters.[50] The effect plays out equally: pumping from the alluvial aquifer can have an effect on surface flows, and diversion from surface flows can have an impact on water levels in an aquifer.

In 1969, Colorado passed "The Water Rights Determination and Administration Act."[51] This legislation is important as it requires all tributary groundwater to be included with surface water when determining priority under the prior appropriation system of water distribution.[52] Colorado's water courts presume an interconnection between surface and groundwater resources. [53] This means that in a dispute between water users, the system

[44] Or. Admin. R. § 690-009-0040(4)&(5).
[45] *Waterwatch of Oregon, Inc. v. Water Resources Commission*, 199 Or. App. 598, 608 (2005).
[46] Or. Rev. Stat. § 390.835(9)(a) (2009).
[47] *Id*. at § 390.835(9)(b).
[48] Colo. Const. art. XVI §§ 5, 6.
[49] *See generally*, *Empire Lodge Homeowners' Ass'n v. Moyer*, 39 P.3d 1139 (Colo. 2001).
[50] *Id*. at 1150.
[51] *See*, Colo. Rev. Stat. § 37-92-101 to 602.
[52] Colo. Rev. Stat. § 37-92-102.
[53] *Bd. of County Comm'rs v. Park County Sportsmen's Ranch, LLP*, 45 P.3d 693, 702 (Colo. 2002) ("Colorado law contains a presumption that all groundwater is tributary to the surface stream unless proved or provided by statute otherwise.").

will be viewed as if the surface water and groundwater is interconnected and treated under the Conjunctive Management standards, unless proved otherwise.[54]

Given its strict policies recognizing the connections between water sources, Colorado began a system of "Augmentation" to allow groundwater users to continue to exercise their water use rights and avoid curtailment in drier years.[55] These court approved "Augmentation Plans" work to allow a junior appropriator to use water, so long as the user has a plan in place to replace the water used that negatively affects senior water users.[56] Additionally, the Augmentation Plans are able to take advantage of the delayed effect pumping has on surface rights, giving groundwater users time to supplement the surface rights.[57]

The Colorado model for Augmentation Plans is a simple concept: A junior water right holder is allowed to divert water out of priority so long as the junior water right holder supplements the surface flows before the senior water right user "calls" for water diversion on their senior water rights of use. In its practical application, the State requires the junior water right holder to show proof of the amount, timing, location, and impact of the diversion, and exactly how such impact is mitigated under an approved Augmentation Plan.[58] Until such proof is furnished, the junior appropriator may not divert water.

Idaho

Like Oregon and Colorado, Idaho is a prior appropriation state.[59] This "first in time, first in right" principle of water resource management has been used in Idaho since the state constitution was adopted in 1890.[60] Both surface and groundwater in Idaho are managed together under a single statutory scheme.[61]

In 1994 Idaho passed the "Rules for Conjunctive Management of Surface and Ground Water Resources," putting in place very specific procedures for managing the ground and surface water in the State.[62]

Consideration is given to whether uses of surface and groundwater sources will affect one another. The rules outline criteria for determining whether water sources are connected: "The ground water source supplies water to or receives water from a surface water source; or Diversion and use of water from the ground water source will cause water to move from the surface water source to the ground water source."[63]

Similar to augmentation plans in Colorado, Idaho created a system in which junior users can avoid curtailment if they submit an approved "Mitigation Plan."[64] These Mitigation

[54] *Id*.
[55] *See*, *Id*. at 696.
[56] *See generally*, *Empire Lodge Homeowners' Ass'n v. Moyer*, 39 P.3d 1139, (Colo. 2001).
[57] In Colorado, the Upper Arkansas Water Conservancy District uses augmentation plans which cover hundreds of wells, and are used to offset stream depletions caused by ground water pumping.
[58] Colo. Rev. Stat. § 37-92-305(8).
[59] *See*, *Malad Valley Irrigation Co. v. Campbell*, 2 Idaho 411, 414 (Idaho 1888).
[60] Idaho Const. art. XV, § 3.
[61] *See*, Idaho Code Ann. § 42-103.
[62] Idaho Admin. Code Proc. Act. 37.03.11.
[63] *Id.* at Rule 31.03.
[64] *Id*. at Rule 42.02.

Plans prevent injury to senior water users by providing "replacement water supplies or other appropriate compensation to the senior-priority water right during a time of shortage even if the effect of pumping is spread over many years and will continue for years after pumping is curtailed."[65]
Further, the Idaho State Water Plan notes that "[w]here a hydraulic connection exits between ground and surface waters, they should be conjunctively managed to maintain a sustainable water supply."[66] Idaho's water resources are managed in a way to "optimize the benefits."[67] The State Water Plan identifies a number of implementation strategies, including: 1) working to quantify ground and surface water connection, 2) listing basins in need of additional information to determine ground and surface water interaction, 3) creating tools for evaluating connection, 4) estimating rate of aquifer recharge and depletion under varying climactic conditions, and 5) funding.[68]

<u>Washington</u>

Washington is also a prior appropriation state.[69] Like Colorado and Idaho, Washington recognizes that some groundwater is connected to surface water, and some is not. To the extent that groundwater is considered a tributary to surface water sources, the subsequent groundwater use right is deemed inferior to the senior surface water use right, and regulated accordingly to give effect to all diversion/appropriation dates of priority.[70]

In 1971, the Washington legislature passed the "Water Resources Act of 1971." The purpose of the 1971 law is stated to provide "[p]roper utilization of the water resources of this state is necessary to the promotion of public health and the economic well-being of the state and the preservation of its natural resources and aesthetic values."[71] One of the fundamentals of the act includes: "Full recognition shall be given in the administration of water allocation and use programs to the natural interrelationships of surface and ground waters."[72]

As with most states' application of Conjunctive Management, the issue of "hydrological connection" is key to its implementation. The Court of Appeals of Washington faced this issue in the case of *Hubbard v. Department of Ecology*.[73] This decision involved a challenge to the Department of Ecology's determination that a groundwater aquifer was connected to a surface stream. The Court found that senior surface rights were superior to the groundwater rights as there was "significant hydraulic continuity."[74] The Court clarified that the term "significant" is not referring to the severity of the effect of the appropriation, but rather that the effect "would eventually reach the river in the form of

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[65] *Id*. at Rule 43.03.
[66] Idaho State Water Plan Sec. 1E.
[67] *Id*.
[68] *Id*.
[69] Wash. Rev. Code § 90.03.250.
[70] Wash Rev. Code § 90.44.030.
[71] Wash. Rev. Code § 90.54.010.
[72] Wash. Rev. Code § 90.54.020(9).
[73] *Hubbard v. Department of Ecology*, 86 Wn. App. 119 (Wash. Ct. App. 1997).
[74] *Id*. at 125.

reduced flow."[75] In other words, the Court found that any effect on the surface water source allowed the Department of Ecology to reject or condition an application to appropriate groundwater.

Nevada

Nevada is a prior appropriation state, and any person who wishes to use waters of the state must apply to the State Engineer for a permit.[76] The State Engineer shall reject a permit "where there is no unappropriated water in the proposed source of supply, or where its proposed use or change conflicts with existing rights…or threatens to prove detrimental to the public interest…"[77] This standard applies to both surface and groundwater appropriations.[78]

Although groundwater appropriations are regulated in the same manner as surface waters,[79] Nevada has no express statutory scheme in place for Conjunctive Management of surface and groundwater. Applications for new and changed uses must be rejected if they conflict with "existing rights,"[80] but many water rulings in Nevada continue to ignore known relationships between groundwater appropriations and reduced surface flows focusing on a statutory distinction between surface and groundwater based upon the application made rather than the conjunctive nature of water.

Although Nevada has a regulatory permitting system for all groundwater use in the State, its system does not account for the interconnectedness of surface water and groundwater. Thus, Nevada is behind most other western states in managing its water resources for sustainability and protection of existing water use rights.

CONCLUSIONS

The Sustainable Groundwater Management Act moves California towards what other states have already undertaken and scientists and engineers have known for years: surface and groundwater resources are in many respects part of a single complex, interconnected water system. However, this is only a step towards achieving a long term sustainable resource in the face of climate change and California will need to continue to improve and refine its laws if it hopes to truly improve groundwater management.

The new groundwater laws envision a decentralized system of groundwater management that will be implemented at the local government level by a large group of newly created "groundwater sustainability agencies" with State oversight. How each agency will be formed from existing or new local entities is unclear and open-ended. Concerns amongst

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[75] *Id*. at. 126, 127.
[76] Nev. Rev. Stat. § 533.335 through § 533.340. There are exemptions from this requirement. *See, e.g*., Nev. Rev. Stat. § 534.013.
[77] *Id*.
[78] Nev. Rev. Stat. § 534.050 (before sinking a well, a person wishing to appropriate groundwater must apply for a permit pursuant to Nev. Rev. Stat. § 533).
[79] Nev. Rev. Stat. § 534.050.
[80] Nev. Rev. Stat. § 533.370(5).

those in the rural and agricultural regions of California are that those same water agencies that lead to the critical groundwater overdraft conditions in those regions will end up being the same groundwater sustainability agencies for their basins.

There is some ambiguity in the legislation about which local agencies will become the groundwater sustainability agency for a particular basin and how multiple agencies will coordinate their efforts. This ambiguity was intentional since there are too many different circumstances across California to legislate a “one-size-fits-all” approach to identifying a groundwater sustainability agency. There is an increased challenge within each local agency in determining how best to manage groundwater, as well as coordinating multiple agencies in large groundwater basins. If the development and implementation of groundwater sustainability plans reaches an impasse, this lack of clarity in the legislation is a likely culprit.

Another drawback is the schedule for implementation, especially given the clear and present danger presented by current, unregulated groundwater over-drafting around the state. State sanctions for non-compliance with the requirement to adopt timely and adequate groundwater sustainability plans don’t kick in until 2020 and, in some cases, not until 2025. And actually *achieving* truly sustainable groundwater basins under even legally adequate local plans is not required for decades. The laws express stated objective is “to achieve the sustainability goal in [a given groundwater] basin within 20 years of the implementation of the plan.”

The Act should be commended for being passed, but should not rest on this fact. Localized management of the resource ensures local communities will be involved and regulators should understand the needs of the specific area. However, without greater demand for information of who is pumping, how much, and for how long, the overall body of knowledge of available groundwater throughout the State will continue to be a problem. In order for local and state groundwater agencies to be able to formulate, implement and enforce truly effective groundwater sustainability plans, this information will be critical. California would also benefit from looking to other Western states which acknowledge the significance of surface-groundwater connections, especially the connection with percolating water in the alluvial zone, and manage these rights together in order to preserve the resource and protect its users.

GOVERNANCE CHALLENGES FOR COMPREHENSIVE GROUNDWATER MANAGEMENT

Steve Macaulay P.E.[1]

ABSTRACT

This paper describes case studies for formation of groundwater sustainability agencies (GSAs) to be developed in response to California's 2014 Sustainable Groundwater Management Act.

California's Sustainable Groundwater Management Act (SGMA) has as its goal the sustainable management of its groundwater resources no later than 2040. SGMA requires that a number of actions be taken early in implementation, including designations of Groundwater Sustainability Agencies (GSAs) in every groundwater basin / subbasin by July 2017. SGMA became law in January 2015, and as of mid-April (when the final version of this paper was prepared) a number of regions had begun discussions on the appropriate geographic and institutional mix of GSAs and Groundwater Sustainability Plans (GSPs).

This paper provide the most up-to-date information on the issues being confronted by water districts and local government in developing appropriate local GSAs, with observations about how such deliberations will contribute to the overall goal of sustainable groundwater management.

This paper is a complement to similar papers on groundwater management in other western states being presented at the June 2015 conference in Reno. The author is a consultant to the California Department of Water Resources (DWR) for implementation of SGMA. Material presented in this paper is based on information developed in recent public meetings and through DWR's groundwater web site (http://www.water.ca.gov/groundwater/).

INTRODUCTION

The concept of state groundwater legislation in California has been discussed for many years. As background, direct control by state government of surface waters came about through the adoption of the Water Commission Act of 1914. This set in place the current surface water appropriative water system whereby water users are issued a water right permit for the beneficial use of such water supplies. The legislative deliberations leading to the adoption of the 1914 Act considered whether the state would have permitting and management authority over groundwater extractions, but ultimately was limited to surface water rights.

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It took a full 100 years before the California Legislature supported any degree of regulatory control over groundwater extractions (other than court-ordered adjudications), driven by the concerns over increasing groundwater overuse, the importance of reliable groundwater resources to the economy, and conditions of the ongoing serious drought. Governor Jerry Brown signed SGMA into law in September 2014 at the end of what was a third consecutive drought year.

As outlined in a separate paper by Macaulay and Joseph, SGMA sets forth a number of requirements and timelines for establishing GSAs and for eventual development of GSPs. SGMA requirements include: (1) designation of basin priorities (only medium and high priority basins are required to form GSAs and develop GSPs); (2) consideration of groundwater basin boundary adjustments to boundaries that were developed by DWR over the past 30-40 years; and (3) consideration of the necessary components of a GSP (regulations to be developed by DWR). There are many more requirements, but these are critical for local agencies to form GSAs.

SGMA ELEMENTS RELATED TO FORMATION OF GROUNDWATER SUSTAINABILITY AGENCIES

In the best of all worlds, these three SGMA requirements would be established in DWR regulations long before GSAs are formed. However, the law takes a concurrent rather than linear approach, making it more difficult to form GSAs by the legal timeline while the other requirements are in play. Table 1 below shows the deadline for each requirement in chronological order.

SGMA Requirement	Due Date
DWR: prioritize groundwater basins	January 31, 2015
DWR: adopt basin boundary revision regulations (after which applications for boundary adjustments can be submitted)	January 31, 2016
DWR: adopt regulations specifying GSP components	June 1, 2016
Local agencies: establish GSAs for medium and high priority basins	July 1, 2017

Table 1. Timelines for Various SGMA Requirements

While this appears linear with the establishing of GSAs at the end, the formation of GSAs is expected to be a long and difficult process and will in many cases depend on what will eventually end up in the various DWR regulations. It is largely acknowledged that discussions regarding GSA formation need to get underway immediately. In fact, as of April 2015 dialogue at many levels had been actively underway on this topic. Recognizing the importance of this dialogue, DWR has offered limited no-cost facilitation services to help promote such discussions.

<u>Basin Priorities</u>

GSAs and resulting GSPs are required of all groundwater basins that are of medium or high priority. An early SGMA requirement was to adopt basin priorities. In 2009 a new law went into effect that required DWR to develop the California Statewide Groundwater Elevation Monitoring (CASGEM) program. CASGEM was developed to track seasonal and long-term trends in groundwater elevations in California's groundwater basins. Fortunately the CASGEM program had developed groundwater basin priorities as of June 2014, and DWR adopted those priorities in January 2015 as the initial SGMA priorities. Figure 1 is a map showing statewide basin priorities.

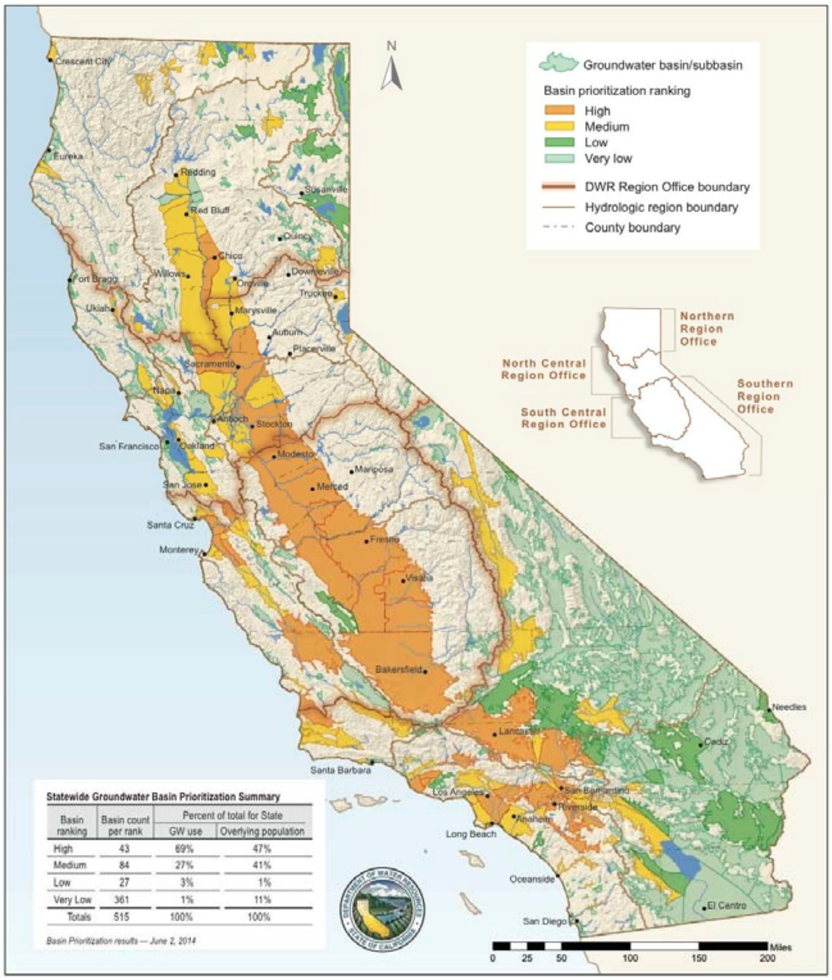

Figure 1. CASGEM Groundwater Basin Prioritization

The 2009 law required that the CASGEM program prioritize each of the groundwater basins using the following factors:

1. Overlying population
2. Projected growth of overlying population
3. Public supply wells

4. Total wells
5. Overlying irrigated acreage
6. Reliance on groundwater as the primary source of water
7. Impacts on the groundwater; including overdraft, subsidence, saline intrusion, and other water quality degradation
8. Any other information determined to be relevant by DWR

While SGMA added “including adverse impacts on local habitat and local streamflows” to factor 8 above, this did not change initial basin priorities although it may change such priorities in the future as more information and data is developed on this matter.

DWR’s extensive website on groundwater resources (http://www.water.ca.gov/groundwater/) includes this description of California’s extensive groundwater basins:

> *There are 515 alluvial groundwater basins and subbasins in California as defined in DWR's Bulletin 118. These basins contribute close to 40 percent of the California's annual water supply in an average year and as much as 45 percent in dry years. During extensive dry or drought years, groundwater can provide close to 60 percent of the water supply. Statewide, approximately 30 million people, or 80 percent of Californians, live in areas overlying alluvial groundwater basins. Some communities are 100 percent reliant on groundwater.*

Basin Boundary Adjustments

Current statewide basin boundaries are published in DWR’s Bulletin 118-2003. While the boundaries are largely established based on hydrogeologic factors, they also consider political boundaries. SGMA provides for the possibility of existing boundaries being modified for the purpose of implementation of the law, and DWR is required to adopt regulations for basin boundary revisions by January 31, 2016.

As of April 2015 DWR staff had met with more than 50 specific water interests and groups to hear what they had to say regarding the need to adjust boundaries in their regions. Public “listening sessions” are scheduled to get public input on basin boundary adjustments, and a Practitioners Advisory Panel had been formed to provide technical and institutional input. A number of concerns have been raised, including the need to reflect boundaries of agencies that make water resource management decisions within their boundaries that do not necessarily match groundwater basin boundaries. It was made clear in many of these meetings that the local agencies managing surface water resources are likely to play important roles in achieving sustainable groundwater management, and that success in meeting sustainable groundwater objectives will mean overall sustainable water management.

Another concern raised to date by local agencies is the interplay among water district boundaries, county boundaries and groundwater basin boundaries. In some cases local agencies have indicated that county boundaries might work best. In other cases, especially where groundwater basin boundaries crossed over county boundaries, there were mixed recommendations depending on various circumstances in different regions. A common concern appeared to be how to handle groundwater use areas that are not within water districts.

Groundwater Sustainability Plan Components

The actual requirement in SGMA is reproduced below:

> *10733.2. DEPARTMENT TO ADOPT EMERGENCY REGULATIONS CONCERNING PLAN REVIEW AND IMPLEMENTATION*
>
> *(a) (1) By June 1, 2016, the department shall adopt regulations for evaluating groundwater sustainability plans, the implementation of groundwater sustainability plans, and coordination agreements pursuant to this chapter.*
>
> *(2) The regulations shall identify the necessary plan components specified in Sections 10727.2, 10727.4, and 10727.6 and other information that will assist local agencies in developing and implementing groundwater sustainability plans and coordination agreements.*

These regulations will be intended to identify necessary GSP components and describe how DWR will determine whether the sustainable groundwater management objectives and actions developed by GSAs meet the intent of the law.

Land Use Control

It is important to recognize that not all irrigated lands in California are within a water or irrigation district, and that achieving long-term groundwater sustainability may require reduction in groundwater extractions in some basins over time. Decisions on land use in California are largely at the local level, with decisions by cities made within municipal boundaries and decisions made in unincorporated areas made by county government. SGMA establishes the counties as a default GSA or partner in a GSA, presumably to ensure that land use authority is one of the tools for GSPs.

CASE STUDIES: CHALLENGES AND INITIAL EFFORTS IN SELECTED REGIONS OF CALIFORNIA

For almost 20 years California state government has allowed and encouraged the development of groundwater management plans, and in recent years such plans have included measureable basin management objectives. This has been a voluntary program, with grant funding available to those organizations that wished to develop a plan. In addition, for more than a decade state government has also promoted the development of integrated regional water management, including the development of integrated regional water management plans (IRWMPs).

As described earlier, CASGEM was developed to track seasonal and long-term trends in groundwater elevations in California's groundwater basins. The law requires collaboration between local monitoring entities and DWR to collect groundwater elevation data.

All of these programs – all largely voluntary for local agencies and water users -- have formed important building blocks for statewide sustainable water management. While voluntary, each program has had major success – in part due to the availability of supporting bond funds, and in part due to the need to develop groundwater management plans, IRWMPs and implement CASGEM in order to get future state funding for water management support.

The four case studies below (general locations shown in Figure 2) describe the historic development of groundwater management in each of the subregions, as well as the challenges each face as they seek to develop groundwater sustainability agencies to comply with SGMA.

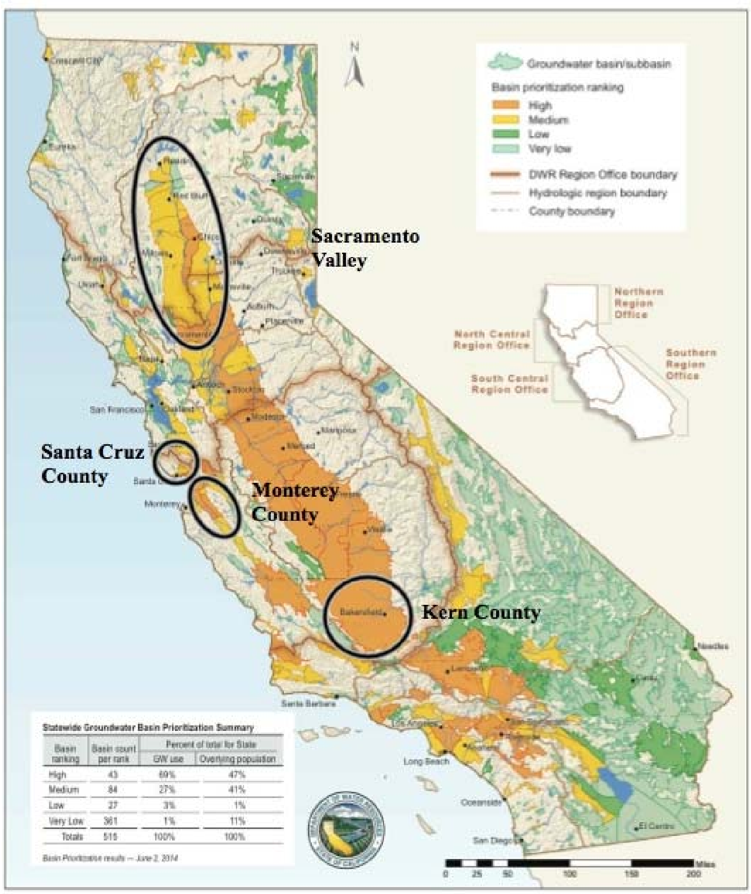

Figure 2. General Location of Case Studies

<u>Sacramento Valley</u>

Sacramento Valley is essentially a large alluvial region on the Valley floor, with two primary groundwater basins (Tuscan and Tehama formations) divided by DWR into a large number of subbasins. The subbasins are shown in Figure 3. The figure also has county boundaries should in the background. While water district boundaries are not shown, they are a complex mix throughout the Valley.

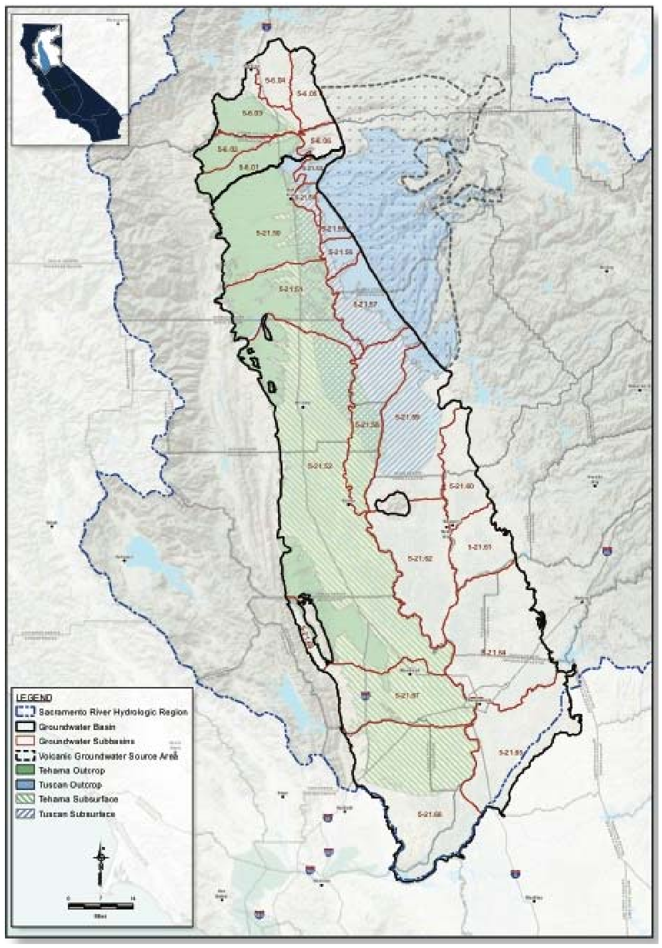

Figure 3. Sacramento Valley Groundwater Basins

In meetings with a number of Sacramento Valley representatives, DWR received many comments about the complex institutional relationships that exist throughout the Valley. The least complex is Yuba County on the east side of the Valley, which has boundaries formed by three rivers. Water leadership is essentially the same as between the Yuba County Water Agency and the Yuba County Board of Supervisors, and water resources are effectively managed within the County boundaries. Several districts (e.g. Glenn-Colusa Irrigation District, Reclamation District 108 and the Tehama Colusa Canal Authority) overlap two or more counties. Such water districts effectively manage their surface water resources – and to some extent groundwater extractions – only within heir boundaries and have no authority over adjacent areas that pump groundwater for irrigation needs. Some districts also overlap groundwater subbasins.

Effective management called for in SGMA may warrant modification to the groundwater subbasins shown in Figure 1. The Northern California Water Association has suggested that there would be merit in dividing much of the Sacramento Valley along county lines for a variety of reasons including the jurisdiction of the counties under SGMA in the unmanaged areas.

Kern County

The Central Valley portion of Kern County is extensively irrigated, with water supplies managed by a large number or water and irrigation districts. A map of most of these districts is shown in Figure 4. The collective boundaries of these districts essentially overly the large groundwater basin in this region.

The entire Kern groundwater subbasin is classified as high priority under SGMA, and has a long history of both overdraft and extensive water management. The region has a number of surface water sources including water imported from other regions. Surface water distribution facilities are located throughout the subbasin, each controlled by a different entity with different sources of surface water. The subbasin is highly dependent on groundwater in dry years, when surface water supplies are low.

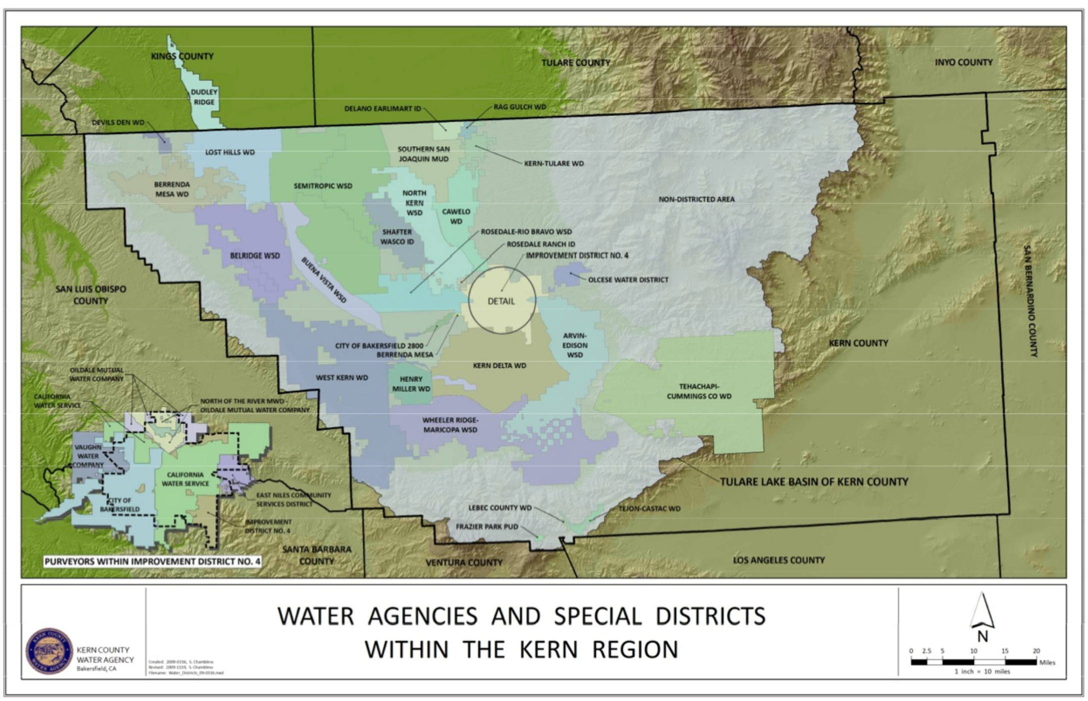

Figure 4. Water Districts in Kern County

Most of the districts in Figure 4 have recently formed the Kern Groundwater Authority (KGA) to respond to the challenges brought about by SGMA. The KGA is currently engaging in an open dialogue of how water interests in Kern County should appropriately address the requirements of SGMA. They recognize that SGMA allows several options for developing SGPs within a basin, and the ongoing dialogue is exploring the concept of forming multiple GSAs and either multiple GSPs or a single GSP with a number of chapters addressing the implementation plan for each of the KGA member agency areas.

Water agencies in Kern County are historically very engaged in water management issues, and frequently work together on common issues. They are raising a number of issues related to SGMA compliance, mostly associated with the interplay between GSAs ands GSPs and how that plays into current institutional boundaries. The SGMA issues in this region are primarily institutional, but are important to successful attainment of sustainable groundwater management.

<u>Monterey County</u>

Figure 5 shows a map of groundwater basins in both Monterey County and Santa Cruz County, along the California coast.

Figure 5. Groundwater Basins in Monterey and Santa Cruz Counties

Water agencies in Monterey County have raised several concerns. First, various State agencies involved in water supply and water quality do not provide consistent and often conflicting guidance when implementing State Agency programs. In particular they were concerned about coordination with the State's salinity and nutrient management regulatory program as it may affect SGMA implementation.

Second, Monterey County has not yet complied with provisions of the CASGEM program, limiting heir access to future State bond funds. Recognizing this limitation, they have begun working to provide all necessary information to DWR in order to reach compliance in all of the remaining unmonitored groundwater basins in their area.

A third complex issue is how to address SGMA requirements for the Carmel River watershed, due to the very complex nature of water rights and groundwater extractions in this small but important watershed. A key issue in that watershed is concern over adverse impacts of pumping on surface water flows.

A fourth issue is a need for a basin boundary modification in the southern portion of the County due to the presence of a physical groundwater divide that is not reflected in current basin boundaries.

A final issue relates to longstanding seawater intrusion, and how that is impacted by groundwater diversions in a nearby adjudicated groundwater basins (adjudicated basins are not subject to SGMA). The concern is that pumping in both the adjudicated and non-adjudicated basins has the potential to further aggravate seawater intrusion, and direct participation by the adjudicated basin in a GSA and subsequent GSP might be desirable.

Santa Cruz County

The City of Santa Cruz, County of Santa Cruz, Soquel Creek Water District, Scotts Valley Water District, Pajaro Valley Water Management Agency and others have been working actively for several years on more active engagement in sustainable groundwater management. They have begun active discussions on forming appropriate GSAs, taking into consideration a number of related factors including potential groundwater basin boundary adjustments and the interaction between groundwater extractions and surface water resources.

A number of technical concerns have been raised concerning SGMA implementation in Santa Cruz County. There is a concern that there is little scientific basis for three of the basins in the County, and it may make sense to combine them. Due to the dipping of geologic groundwater bearing formations, a significant amount of pumping in formations east of the Pacific coast is causing impacts to down gradient groundwater basins. In addition, the County of Santa Cruz has documented groundwater basin boundaries as part of their current groundwater management plans, and they do not correspond to current DWR-developed boundaries.

The current low-priority Scotts Valley basin is completely reliant on groundwater, and it may make sense to increase the priority in order to allow the basin to develop a GSP. In addition, there is a concern that groundwater pumping in this small, confined basin is impacting flows in the nearby San Lorenzo River. The interaction between groundwater extractions and surface water resources is one of the elements added by SGMA for groundwater basin priorities.

Finally, the primarily agricultural Pajaro Valley overlaps both Santa Cruz and Monterey counties. Basin boundaries, GSAs and GSPs need to account for this physical fact, particularly since Pajaro Valley Water Management Agency is one of the few organizations that is defined as an exclusive GSA in SGMA.

CONCLUSIONS

SGMA implementation will require major changes over the long-term in how water agencies and local government in California manage or oversee water supplies. The case studies in this paper showcase a number of complex technical and institutional challenges that will need to be addressed, and reinforce the importance of tailoring water management solutions to complex local needs.

While not specifically addressed in the case studies, a common concern is promoting effective outreach and communication as SGMA implementation goes forward. Efforts at broad local dialogue have begun throughout California, against the backdrop of a fourth consecutive year of drought. By June 2016 the California Department of Water Resources will have adopted a number of regulations required for SGMA implementation, after which local agencies will need to form groundwater sustainability agencies and eventual groundwater sustainability plans.

This paper is written as a companion to other papers on the general topic of California’s 2014 Sustainable Groundwater Management Act that will be addressed as part of the June 2015 USCID Conference in Reno.

FEATHER RIVER REGIONAL AGRICULTURAL WATER MANAGEMENT PLAN

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ABSTRACT

A regional agricultural water management plan has been prepared for California water suppliers diverting from the Feather River. The Feather River Regional Agricultural Water Management Plan (FRRAWMP) describes water resources of and management by participating suppliers. Regional agricultural water management planning provides an opportunity to evaluate water management at farm, district, and regional scales, demonstrating the effects of local and regional reuse of water diverted but not consumed on water use efficiency. Return flows from irrigated agriculture in the region are critical to support important aquatic and terrestrial ecosystems and to provide water supplies for other downstream water users. Water diverted but not consumed within the region is available to meet additional environmental, agricultural, and urban needs downstream. The plan documents past, current, and potential future implementation of Efficient Water Management Practices (EWMPs) within the region to improve water use efficiency. The fact that water diverted but not consumed is available to provide additional benefits within or downstream of the region underscores that the primary objective of water management should not necessarily be to reduce diversions but rather to optimize the timing and location of water use for multiple purposes. In other words, the key question is "Where do you want the available water and when?"

In order to enhance water management capabilities of water users in the region, comprehensive appraisal-level modernization plans were developed for all participating water suppliers. A total of $85 million in potential water management improvements were identified that could be implemented to provide multiple benefits from local to statewide perspectives. It is anticipated that these improvements, or refinements to them, will be implemented over time on a strategic basis subject to the availability of local and other funding sources.

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DEVELOPMENT OF AN IDEAL GROUNDWATER RECHARGE PROJECT — LAGUNA IRRIGATION DISTRICT RECHARGE BASIN NO. 11

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ABSTRACT

The Laguna Irrigation District Recharge Basin No. 11 is a 50-acre groundwater recharge project located near the North Fork of the Kings River in Kings County, California. The project site has been considered a highly favorable location for recharge for several decades. The site has been under further investigation in feasibility studies performed in 2007 and 2012. In the 2007 study, the project site was identified as the best location for recharge in a 200 square mile study area, specifically in an area that is chronically short of surface water and experiencing groundwater overdraft. In the 2012 study, it was estimated that the project would yield up to 2,650 acre-feet of water per year. The site has many favorable characteristics including permeable soils and geology with high sand content, proximity to two conveyance facilities, located in an existing topographic depression, ideally located in relation to surface water deliveries and groundwater flow, wide public support, excellent economics, and many others. The project also has multiple uses and can serve as a regulation or flood control reservoir for adjoining surface water conveyance facilities. In 2012, the project was conceived and funded through the efforts of several multi-agency organizations, and is an excellent model for regional water management and multi-agency collaboration. The project was constructed utilizing district forces who were highly involved with the project design. The project design centered on ease of construction by District forces to prevent the need for unique trade skills for construction. The design incorporates features to limit District staff from having to enter the basin during recharge operations to limit the potential for injury. The project also includes several special design features to simplify construction and reduce construction cost.

INTRODUCTION

The Laguna Irrigation District (LID) is a 35,197 acre agricultural irrigation district near Riverdale in Fresno and Kings Counties, California. LID is a conjunctive use District that delivers surface water supplies to its customers and its groundwater recharge ponds. The District's water supply is dependent upon the Kings River watershed, with the annual supply difficult to predict. The majority of the water has traditionally been stored within the snowpack with spring and summer melts of the snowpack flowing into Pine flat Reservoir. Laguna Irrigation District is allocated a percentage of the water kept at Pine Flat Reservoir based upon a water schedule administered by Kings River Water

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Association (KRWA). LID lies within the Kings Groundwater Sub-basin, which has been identified as being critically overdrafted.

In an effort to improve groundwater supplies, and regulate Kings River flows, the District has developed a groundwater recharge basin on a 50 acre parcel, called Recharge Basin No. 11. The project site was identified as the most promising location for recharge in an extensive geographic area, and has many characteristics favorable for developing a recharge basin. Project elements include a groundwater basin with levees, water control structure, expansion of a delivery canal and monitoring wells. **Figure 1** is a project location map.

The motive for the proposed project is to address groundwater overdraft and beneficially use floodwaters that flow out of the region. The project will capture and recharge on average 2,650 acre-feet (AF) of Kings River floodwater per year. As a result, the project will capture and recharge water in an area with declining groundwater levels, divert floodwater to reduce flood damage along the Kings River corridor, and create a dry-year water supply that can be pumped by private wells and used in droughts. The project will also create a regulation reservoir that can temporarily hold water and deliver it to irrigators. Lastly, the project will improve local groundwater quality by recharging high-quality Kings River water that originates in the Sierra Nevada mountains.

FEASIBILITY STUDY

The project was identified as a prospective recharge site over 30 years ago, but the first formal study was not completed until 2007 by the Kings River Conservation District (KRCD), with a subsequent study in 2012 by the Laguna Irrigation District. KRCD was awarded a grant from the California Department of Water Resources to identify and evaluate potential groundwater recharge sites in the North Fork area of the Kings River. The North Fork Conjunctive Management Group (North Fork Group) consists of six water agencies in western Fresno and Kings Counties that work collectively to advance water management projects in their area. This study was limited to the area served by the North Fork Group member agencies and covers about 200 square miles (128,000 acres).

The study included a 4-phase process:

1) Identify Potential Recharge Sites. These were identified primarily by local water managers familiar with sites that had coarse grained soils, landowners that may be interested in selling the property, and other favorable characteristics.
2) Rank Sites Based on Practical Factors and Regional Geology. The sixteen sites were ranked based on 19 practical factors such as whether gravity delivery was feasible, proximity to conveyance facilities, facility relocations needed, etc. The geology documented in regional geology studies was also considered.

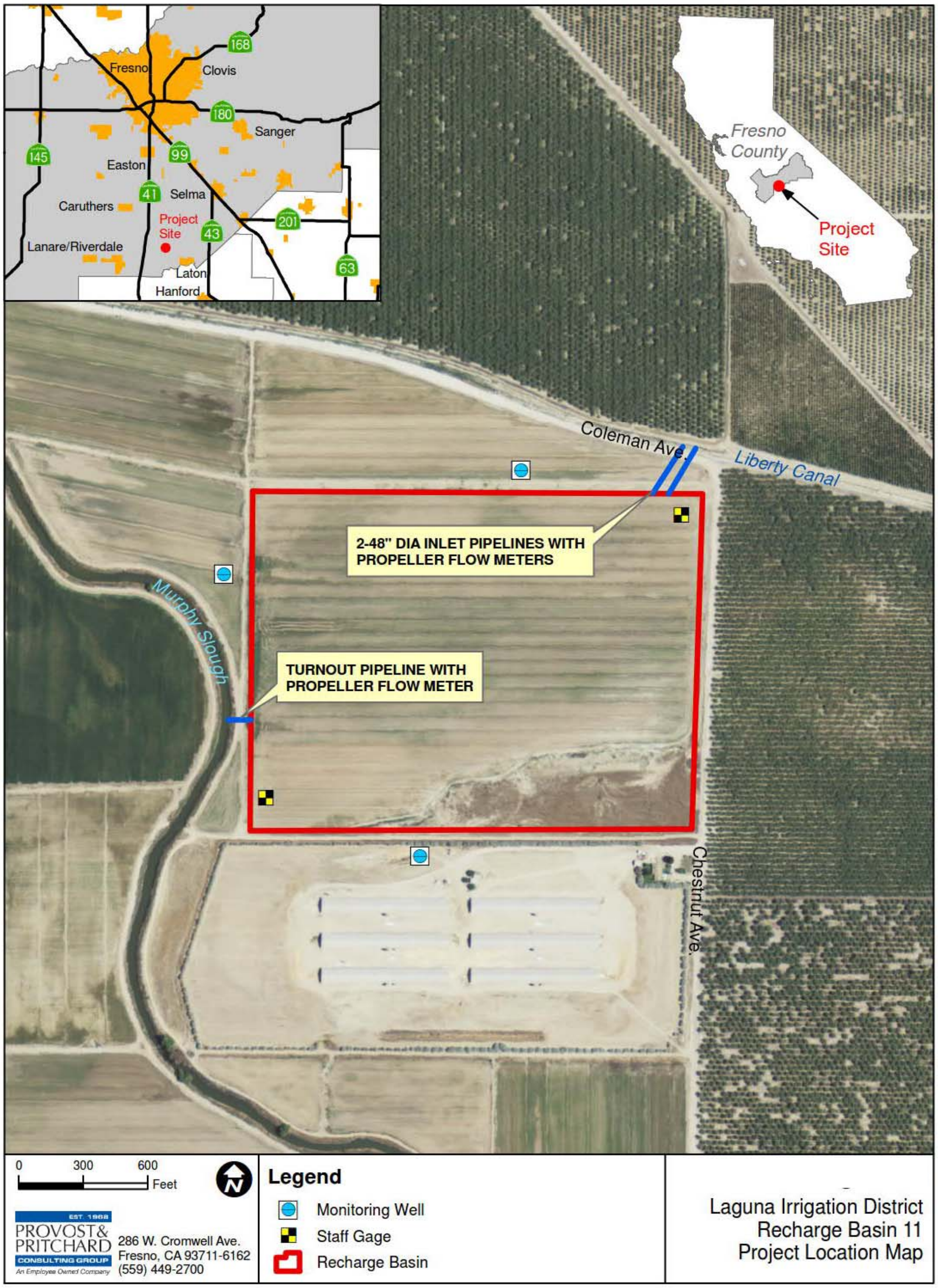

Figure 1. Project Location Map

3) Subsurface Investigations. The seven most promising sites were investigated in more detail through hollow-stem auger drilling, cone penetration tests, laboratory soil classification, and laboratory permeability tests.
4) Rank for Recharge Potential. The seven sites were ranked for recharge potential based on the 19 practical factors and the subsurface investigations. The sites were ranked as Poor, Fair, Good or Excellent.

The sixteen potential sites identified by local growers and water agencies are shown in Figure 2. Each site was evaluated through site visits, discussions with landowners, and an evaluation of physical characteristics, regional geology and local geology. The subsurface exploration program included 2,523 feet of hollow-stem auger drilling, 1,904 feet of cone penetration tests, 51 laboratory grain size analysis tests, and 45 laboratory permeability tests.

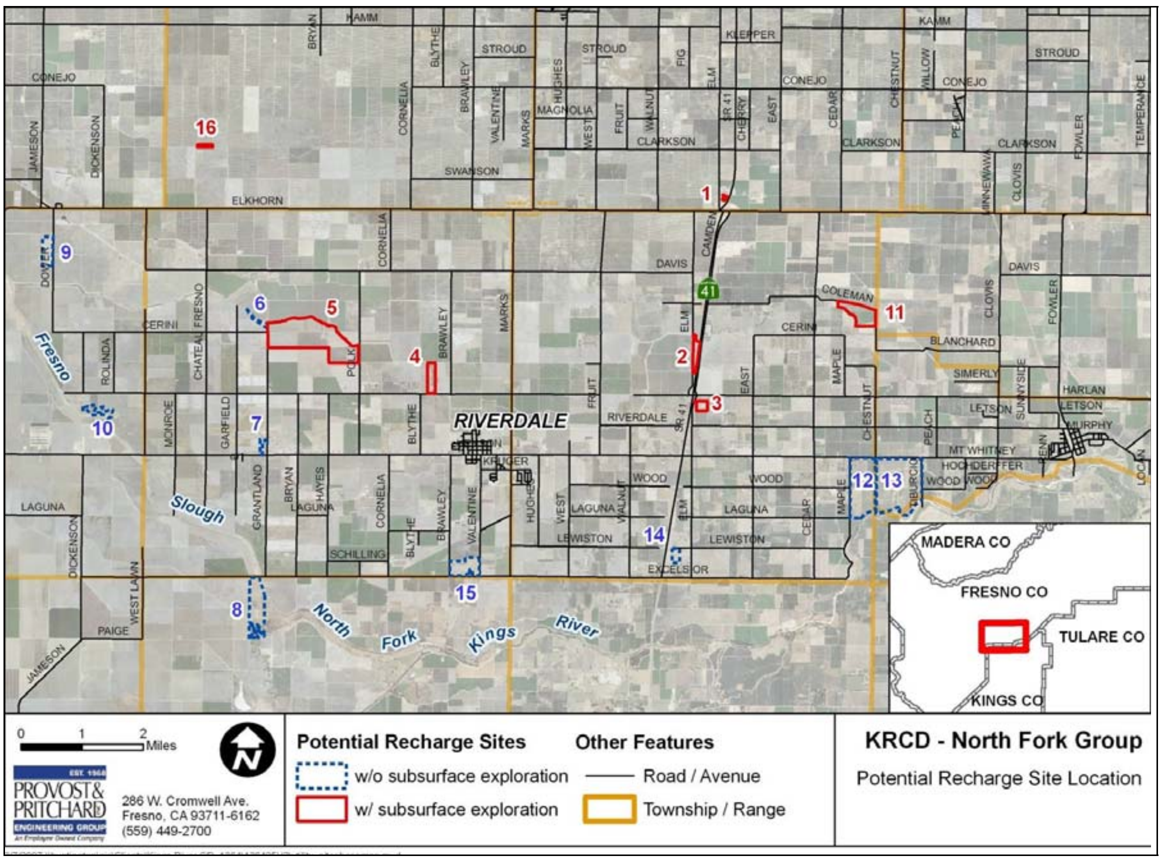

Figure 2. Potential Recharge Site Location Map

The parameters used to rank the sites are listed below:

<u>Land</u>

- Approximate wetted area
- Shape

- Number of landowners
- Current land use
- Accessibility
- Favorable for gravity flow
- Proximity to standing water bodies

Hydrogeology

- Topsoils
- Geologic facies
- Lacustrine clay layers
- Groundwater levels
- Potential for groundwater outflow

Facilities

- Proximity to conveyance facilities
- Capacity of nearby conveyance facilities
- Existing infrastructure
- Relocations needed for development
- Underground utilities

Regulatory issues

- Environmental issues
- Proximity to dairies

The sites were ranked according to their overall suitability for groundwater recharge with the following results:

Table 1. Recharge Basin Site Ranking

Rank		**No. of Sites**
No merit for field investigations		9
Recharge Potential	Poor	1
	Fair	2
	Good	3
	Excellent	1

Recharge Basin 11 was identified as the most promising of the 16 potential sites, and was the only site identified as having '*Excellent*' recharge potential.

SITE DESCRIPTION

The project site was privately owned and was used to grow row crops. However, the landowner had difficulty retaining water with the sandy soils and typically only planted crops in wet years when water was plentiful. The site is also in an existing depression, which was apparently excavated decades ago to provide soil for highway construction. The site is also adjacent to two irrigation canals. These obvious characteristics attracted attention from local water managers who were interested in recharge locations.

Subsurface investigations, including soil borings, cone penetration tests, and soil testing showed that the site had high concentrations of sand. Only a few low permeability layers were found and they appeared to be laterally discontinuous. This is not unexpected considering the depositional environment (primarily fluvial and floodplain deposits), which would have created isolated pockets of coarse and fine grained materials. When the layers are not continuous groundwater can flow around them and they would only be a minor or moderate impediment to groundwater recharge.

Interestingly, Natural Resources Conservation Service soils maps show that the majority of the basin area has soils with ‘very slow infiltration rates’. This is inconsistent with the field investigations. However, most of the surface soils described in the soil survey were removed when the site was excavated years ago exposing more permeable sand. This illustrates the limitations of soil surveys in identifying recharge basins, since they only extend a few feet below the ground surface.

FAVORABLE PROJECT CHARACTERISTICS

The project has many favorable characteristics for a groundwater recharge project making it close to an ideal recharge site. These characteristics include:

1. Favorable soils. The soils have a high sand content. Some clay and silt layers were found, but they do not appear to be laterally continuous and will not be the primary control of infiltration.

2. Better land use. The property is marginal farmland due to its sandy soils. The land is not cropped every year since it has a high water demand due to high infiltration rates. Some of the farmland is designated ‘Unique Farmland’, which is defined by the California Department of Conservation as “*Farmland of lesser quality soils*“. A recharge basin is considered a better use of the land.

3. Adjacent Conveyance Facilities. The project is located adjacent to Liberty Canal which can deliver water directly to the site. The project is also located adjacent to Murphy Slough. Murphy slough has an invert below the ground level and can be used for overflow spills, or to collect water that is temporarily stored in the basin for delivery to irrigators.

4. Topographic depression. The site is located in an excavated depression that allows water to be delivered by gravity, and will reduce the height of levees needed to develop the project. Groundwater mounding in adjacent areas is a small concern since the water will be percolated below the natural ground surface.

5. Area not served by surface water. The project will recharge water in the only part of Laguna ID that does not receive surface water.

6. Groundwater Recharge Study. In the 2007 study the site was identified as the best of sixteen potential sites in the area, and was the only site rated as having ‘Excellent’ potential for groundwater recharge.

7. Local and regional support. The project has widespread support from local and regional agencies including neighboring landowners, neighboring districts, nearby cities, the Kings River Conservation District, and all of the agencies in the North Fork Group.

8. Multi-agency collaboration. The project was identified through a collaborative multi-agency effort when the North Fork Group performed a regional groundwater recharge study in 2007.

WATER SUPPLY

Kings River floodwater would be the primary water source recharged in the basin. Flood release events on the Kings River occur on average about every 3 years. Millions of acre-feet of flood water have been lost from the region because insufficient infrastructure exists to capture and retain these flows.

PROJECT BENEFITS

The project will provide the following benefits:

1. Groundwater Recharge. A simulation of historical Kings River floodwater shows that an average of 2,650 AF/year could be recharged in the basin. Total recharge may be higher if other water supplies are also recharged. The recharged water will help to raise groundwater levels, lower groundwater pumping costs, and provide a dry-year water supply.

2. Regulation reservoir. The project could also be used as a temporary regulation reservoir. The reservoir could temporarily store 144 AF of water, and deliver it to an adjacent slough for delivery to irrigators.

3. Floodwater. The project will have the capacity to divert up to 70 cfs of floodwater. Average annual floodwater diversions are estimated to be 2,650 AF. In very wet years, such as 1968-1969, 1979-1980 and 1982-1983, flood water was available for over 180 days each year. With six months of floodwater, diversions could be as high as 11,000 AF/year. This will reduce water levels and peak flows on the Kings River during flood periods, and thereby potentially reduce flood damage.

4. Habitat creation. The project will create temporary habitat for waterfowl and a water supply for terrestrial creatures when it is filled with water.

5. Water quality improvement. The project will recharge high quality Kings River water in an area with known water quality problems including elevated levels of nitrates and arsenic.

6. Increased Conveyance Capacity. The project will include increasing the capacity of Liberty Canal (from 60 cfs to 110 cfs) for a 5 mile reach. This will allow

delivery to the recharge basin, while meeting full irrigation demands. This increased conveyance capacity will provide other benefits, especially if infrastructure is ever built to deliver surface water to the northern portion of Laguna Irrigation District that does not currently receive surface water.

7. Energy Conservation. Energy will be saved by raising groundwater levels and reducing pumping lifts. It was estimated that annual energy savings will be about 179,000 kwh, which has a value of about $23,000. This also equates to a reduction in greenhouse gasses of 126 metric tons/year.

PROJECT ECONOMICS

The project has many favorable characteristics that make it an economical investment. These include an existing depression that increases storage capacity, water deliveries possible by gravity flow, adjacent canals, landowner willing to sell the property, and high infiltration rate. A financial analysis showed that the project will have a benefit-cost ratio of 3.6:1.

PUBLIC OUTREACH AND REGIONAL COOPERATION

Public outreach was performed to a local city, water district, public utility district, the North Fork Group, several canal companies and to LID landowners. There was widespread support for the project. Four local agencies also pledged to contribute to the project, even though their benefits would be indirect. These contributions ranged from $500 to $1,000 and are more meaningful than a mere letter of support. These contributions were considered important factors that helped LID obtain a larger grant to fund most of the project construction costs.

The project was also conceived and developed through several layers of regional water management involving the North Fork Group, Kings River Conservation District, and Kings Basin Water Authority, and represents an excellent example of regional and local water agencies teaming to identify and implement a successful project.

PROJECT DESIGN

Major Design Criteria

The project was designed with significant input and coordination with LID staff. The two major design components involved: 1) evaluating the potential recharge capacity of the basin; and 2) increasing the conveyance capacity of the Liberty Canal to divert water into the basin while meeting downstream irrigation demands.

The previous feasibility studies concluded that the basin would have an infiltration rate of approximately 0.5 to 1.5 feet per day. Since the site would have a recharge area footprint of approximately 40 acres, the site could recharge up to 60 acre-feet per day, or have an approximate inflow of 30 cubic feet per second (cfs) at the highest infiltration rate. This 30 cfs rate is subsequently treated as the “maintenance flow.” However, it was found that if the basin were to only accept flows at 30 cfs, the basin may not fill or be able to accept higher water volumes of that may only be available for short time periods, such as Kings River floodwater. Therefore, the 30 cfs inflow rate was increased to 70 cfs at the intake to allow the basin to fill at a faster rate than it can recharge, and accept a higher volume of water when flood flows may only be available during a short duration.

The second major design criteria included transporting the basin inflows of 70 cfs through the Liberty Canal while meeting downstream irrigation demands in Liberty Canal. The feasibility study found that the peak demand flows of the Liberty Canal were approximately 60 cfs. It was also known by LID that the Liberty Canal's capacity was limited to 60 cfs due to a series of constraining sections upstream of the basin site. It should be noted, that the location of the basin was approximately 5.5 miles downstream of the headworks of Liberty Canal and once the basin would become operational it would be the first diversion point for flows along the Liberty Canal. Therefore the Liberty Canal would need to have a minimum capacity of at least 130 cfs at the diversion point of the basin. However, LID decided to increase the capacity beyond that of the minimum flow of 130 cfs to 150 cfs. The additional 20 cfs is intended to provide additional capacity in case additional turnout are added upstream of the site or demands downstream of the site increase.

Liberty Canal Evaluation

A tour of the Liberty Canal was performed at the start of the design, and it was determined that an evaluation of the entire Canal would be necessary from the Canal headworks to the basin site. This evaluation of the Liberty Canal started at the downstream check structure in the Canal from the basin diversion to the headworks of the Liberty Canal. Only one constraint was provided on the design of the Liberty Canal; since Liberty Canal Company (LCC) owns and operates the Liberty Canal, and LID is only using the Canal to deliver water to the project site, LCC did not want to have impacts to their diversions of 60 cfs in a channel that will be made larger to convey 150 cfs. This concern arose because the Canal observes a loss of 20% of its diversions from the headworks to the area of the project site. Were the canal to get wider, the 60 cfs flows would run relatively shallow and potentially experience additional losses. Therefore, where physically possible, the Liberty Canal would have a "low flow" channel to minimize these losses.

The Liberty Canal was evaluated in HEC-RAS for 150 cfs with 1 foot of freeboard. This evaluation found the areas that would need improvements. **Figure 3** provides the areas identified of the Liberty Canal that would need to observe improvements to increase the capacity to 150 cfs by the dashed areas. To minimize making the channel too wide for the lower flows, the improvements ranged from raising one back of the canal by six inches to widening the canal by two to three feet and raising the banks by up to two feet. The majority of the improvements only involved minor modifications to expand the capacity.

Basin Design

The design of the basin involved the development of:

- Check Structure in the Liberty Canal capable of passing 60 cfs;
- Turnout into the Basin with a capacity of up to 70 cfs;
- Settling Channel to remove sediment from the flood water that may plug the basin;
- Inter-basin connection, connecting the settling channel to the basin with the capacity of up to 70 cfs;
- A pipeline connection to the Murphy Slough with a capacity of up to 70 cfs; and
- Levee embankment design.

All project components were designed with the consideration that LID staff would construct the project and that the construction methods would need to consider that some District staff have limited experience with larger civil construction projects. These methods included:

- Ensuring that all materials would have a weight that District owned equipment would be able to move around with ease;
- Most structures being precast;
- Pipe and materials being ordered from suppliers that are close and have a consistent reputation for quality;
- All cast-in-place concrete have reinforcement that can easily be placed; and
- Backfill around the pipes would be slurried so the haunches of the pipe would not require extra effort were they to be native backfill.

The hydraulics of the basin were intended to have a inflow capacity of up to 70 cfs, a diversion capacity to the Murphy Slough of up to 30 cfs, and the downstream flows to the Liberty canal of up to 60 cfs.

- The design of the turnout into the basin and the inter-basin connection were designed with a goal of having a combined approximate headloss of one-foot at a flow of 70 cfs. This design includes two 48-inch diameter parallel concrete pipelines for both structures.

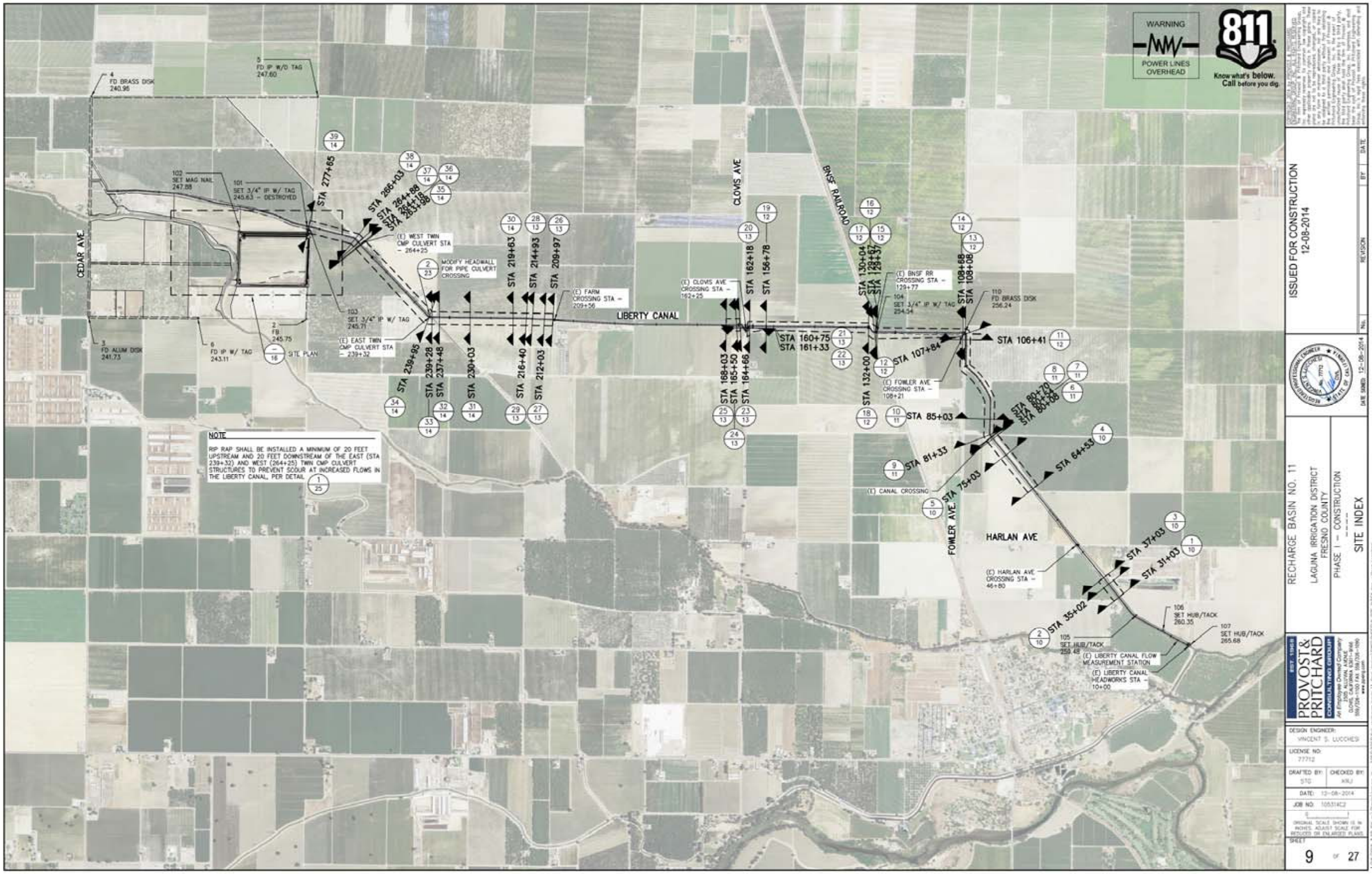

Figure 3. Liberty Canal Map

    - The settling channel design was driven by the hydraulics of the turnout, northern levee length, and the hydraulics of the inter-basin structure. Therefore, the settling channel capability was constrained by the hydraulic ability of the structures. However, at the 70 cfs capacity with one-foot of headloss, the settling channel is estimated to be capable of "settling out" the majority of silt particles that may be suspended in the water.
- Since there was such a large gradient between the basin and the Murphy Slough, the 30 cfs flows from the Basin were not constrained by headloss, therefore the pipe to Murphy Slough was designed to be a single 36-inch diameter pipeline.
- The Liberty Canal Structure was designed to limit the headloss across the structure at peak demands downstream based upon the high water lines at the downstream check structure, therefore the check structure was designed to have two parallel 48-inch diameter concrete pipes.

Levee Design

A geotechnical investigation of the project site provided soil recommendations for the pipeline subgrade, levee keyways, loading criteria of structures and seepage across structures. The geotechnical engineer concluded that the basin levees were stable if constructed with interior slopes of 4:1 ft/ft (horizontal:vertical), exterior slope of 2:1, and levee slopes of the inter-basin levee of 5:1. The levee keyway will be the entire width of all fill and to consist of 18-inches of overexcavation and 8-inches of scarification and compaction prior to fill placement. These criteria are conservative for low levees, but reflect the high sand content in the native soils.

PROJECT CONSTRUCTION

Construction of the basin commenced in December 2014 with the improvements in the Liberty Canal including canal reshaping, raising of banks, and the lowering of the canal invert. As part of the conditions from LCC, LID also compacted the canal banks to reduce the potential for seepage with the increase in canal capacity.

Construction of the basin commenced January 2015 with the excavation of the keyways for the basin levees. Construction of all the facilities is expected by late spring 2015.

CONCLUSIONS

The Liberty Canal Recharge Basin No. 11 was identified over 30 years ago as a favorable recharge site. Within the last year the final design was completed and construction will be completed by late Spring 2015. The project has many ideal characteristics for a recharge basin including sandy soils, located in an existing depression, being located adjacent to two different conveyance facilities, and being located in a small island that does not receive surface water. The project is a good example of multiple agencies working together with a goal of sustainable groundwater management in an area with depressed groundwater levels. This project will provide benefits of groundwater recharge, flood control, water regulation and an increase in canal conveyance capacity.

The design was performed with consideration for District capabilities and desired construction methods to ease and facilitate construction. It is anticipated that monitoring will show the site is a highly productive recharge site.

MODERN GROUNDWATER MANAGEMENT IN THE SACRAMENTO VALLEY

Steve Macaulay P.E.[1]

ABSTRACT

This paper addresses groundwater management in the Sacramento Valley as described in the July 2014 report for the Northern California Water Association (NCWA): Sacramento Valley Groundwater Assessment. NCWA is a voluntary association of water organizations and local government formed in 1992 to present a unified voice to ensure that the Sacramento Valley has reliable and affordable water supplies. That report was prepared by the author, Davids Engineering and West Yost Associates.

The Sacramento Valley has abundant surface and ground water resources, with surface water resources serving as a major source of supply for much of the 2 million acres of irrigated farmland in the Sacramento Valley and extensive urban and agricultural uses in other areas of California (San Joaquin Valley, San Francisco Bay Area and urban Southern California). Groundwater resources support a substantial portion of irrigated farmland, and serve as a source of supply for much of the Valley's population. The ongoing multi-year drought (following a decade of relatively dry years), coupled with increases in water use within the Valley, is putting greater pressures on all water resources. Drought pressures include market-based short-term water transfers involving both surface and ground water. In addition, new acreage is going into irrigation with groundwater as the sole source. Of great importance, only now being broadly recognized by water users and leaders in California, is the importance of the interaction between groundwater extractions and streamflow. This factor will be important as NCWA and its members move forward on their goals to protect water supplies and stream ecological values, preserve and enhance fish and wildlife habitat, and the preserve agricultural productivity.

The paper showcases several case studies of comprehensive groundwater management at the subbasin level, describes the emerging challenges for long-term groundwater resources management, and considers how the Sacramento Valley is positioned for addressing the requirements in California's Sustainable Groundwater Management Act that was enacted as of January 2015.

INTRODUCTION

The location of the Sacramento Valley in the northern portion of the state of California is shown in Figure 1, along with California's major river systems and water distribution facilities. 2015 is the fourth consecutive dry year in California. There continue to be pressures on the Sacramento Valley's water resources and the challenges in providing reliable water supplies for urban, agricultural and environmental water uses. Groundwater

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resources are critical to the region, with groundwater providing nearly 30% of the region's water supplies, with this percentage greatly increasing during dry years – particularly during the current sustained drought.

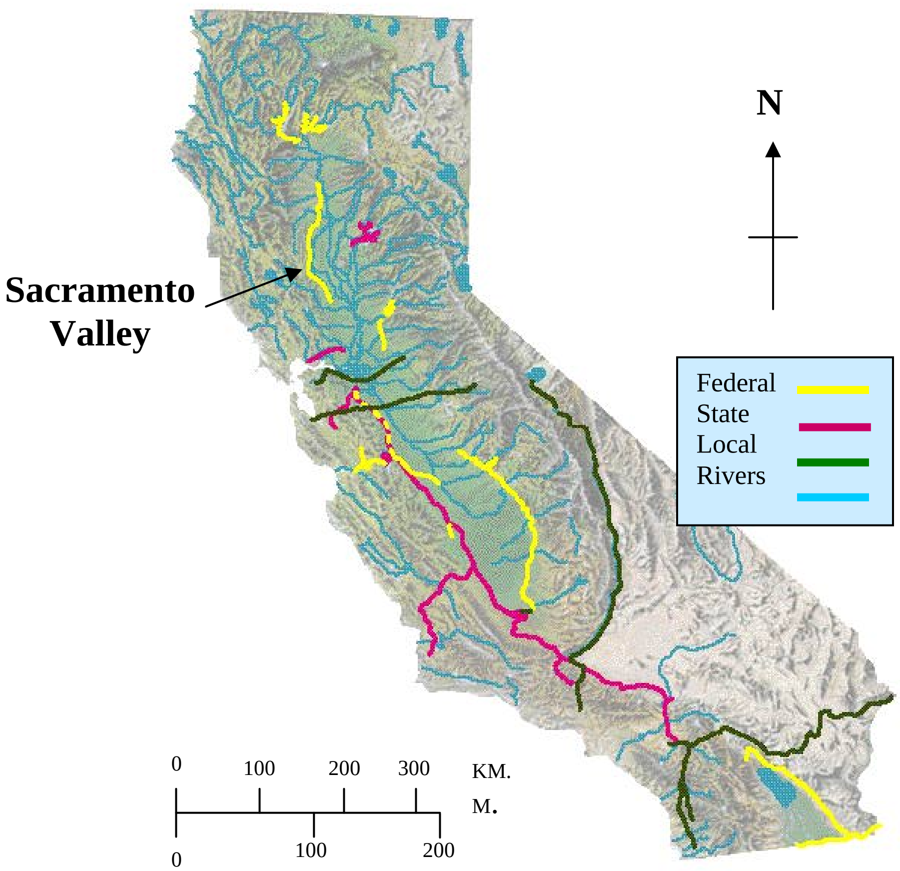

Figure 1. Sacramento Valley, California

The preservation of Northern California's groundwater resources is critical to the economic, social and environmental fabric of the region. As part of this ongoing effort for sustainability, water leaders in the region, through the Northern California Water Association (NCWA), have made a concerted effort over the past several years to assess Sacramento Valley groundwater resources, both for groundwater levels and quality. NCWA's objective is to help bring the region together to actively manage our water resources—both surface and groundwater—to assure sustainable water supplies for cities and rural communities, farms, fish, birds and recreation.

Macaulay Water Resources, Davids Engineering, and West Yost Associates prepared a Sacramento Valley Groundwater Assessment (Assessment) for NCWA, released in July 2014. The Assessment, available through the NCWA web site at http://www.norcalwater.org/efficient-water-management/groundwater-management/, provides an overview of the Sacramento Valley's groundwater resources. The Assessment is in two parts: (1) a 20-page summary document, and (2) a detailed

Technical Supplement with substantial information on historic and recent groundwater and land use trends.

The Assessment provides a discussion on the historical development of land and water resources; the ongoing efforts for sustainable groundwater management; potential effects of increasing use of groundwater; and recommendations for the future. Most importantly, the report summarizes long-term groundwater trends within the Sacramento Valley. Although groundwater levels in the Sacramento Valley have been generally consistent -- draw down during dry years and then recovery in wet years – there are some areas where groundwater levels are not recovering as they have in the past. The Assessment concludes that while there is not yet adequate technical information to distinguish between the impacts of the ongoing drought and what may be longer-term changes to the Sacramento Valley water balance, the lack of surface supplies in some areas and the expanding and intensifying use of groundwater in the Sacramento Valley are contributing to this dynamic. Addressing these challenges will require more active engagement by the water and political leadership in the Sacramento Valley, which is underway.

CASE STUDIES

The Assessment includes a number of case studies of successful groundwater management. Groundwater basins in the Sacramento Valley are shown in Figure 2, which also shows the locations of the case studies described below.

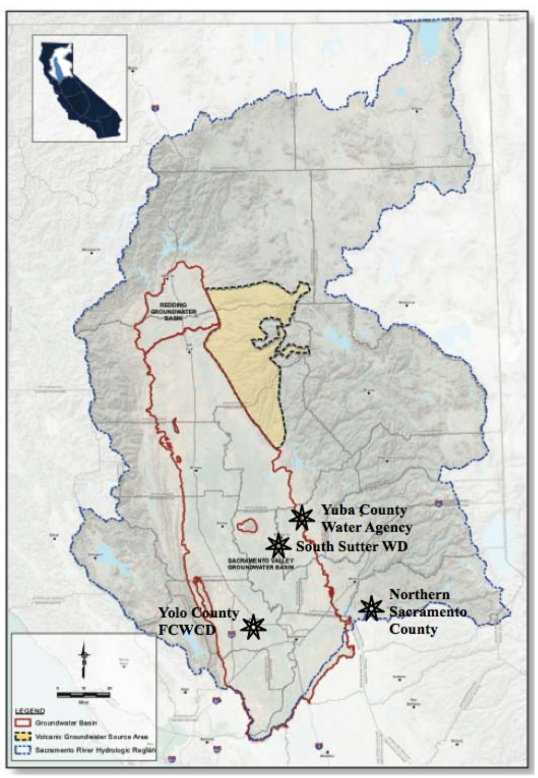

Figure 2. Sacramento Valley, California

South Sutter Water District (SSWD)

SSWD is located in southern Sutter and western Placer counties. The District was formed in 1954 to develop, store and distribute surface water supplies. Today SSWD encompasses a gross area of nearly 64,000 acres. In recent years, due to urban encroachment and other factors, fewer than 36,000 acres in SSWD are irrigated using a combination of surface and groundwater supplies. The dominant crop is rice, accounting for more than 80 percent of the irrigated area.

The primary driving factor for creating SSWD was to develop and distribute supplemental surface water supplies to replenish overdrafted groundwater aquifers. This was accomplished by constructing the enlarged New Camp Far West Dam and Reservoir on the Bear River. These facilities were completed in 1964 creating 104,400 AF of additional storage capacity.

With the delivery of surface water beginning in 1964, groundwater pumping decreased and groundwater levels immediately responded. Groundwater levels have recovered and appear to have stabilized at pre-development levels. The pattern of steady decline before 1964 and recovery afterward is illustrated by the groundwater well hydrograph shown in Figure 3.

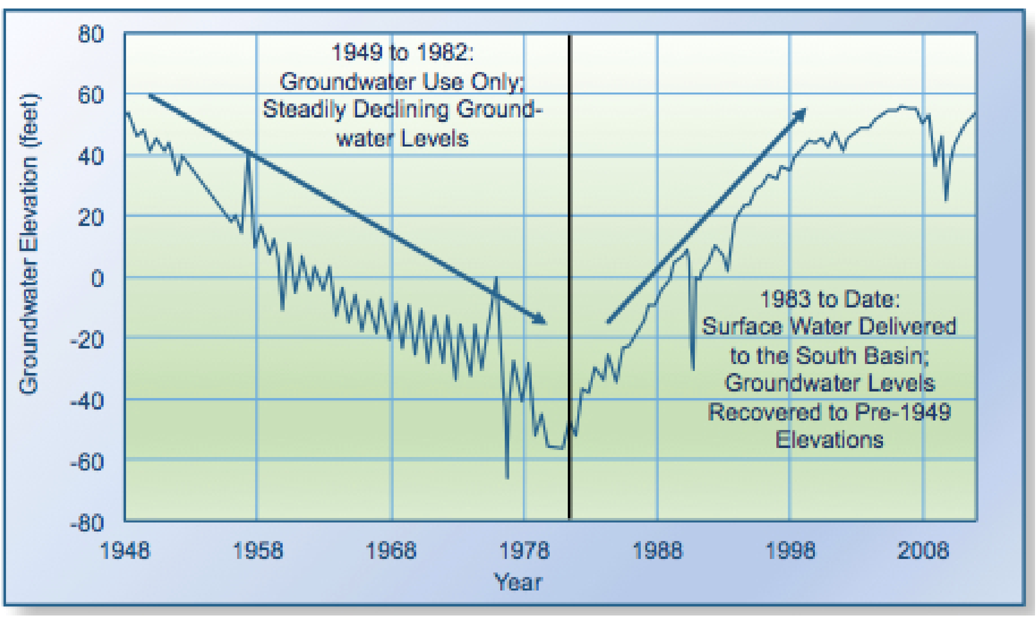

Figure 3. Water Levels in South Sutter Water District Well

Yuba County Water Agency (Agency)

The Agency's early achievement was construction of New Bullards Bar Dam and Reservoir, completed in 1970, to reduce Yuba River peak flood flows and store water for beneficial use. Funding limitations delayed the construction of distribution facilities to deliver surface water to areas that had groundwater levels that had declined dramatically since the early 1940s. In 1983 water deliveries to a portion of the Agency's service area began and the immediate recovery of the groundwater basin commenced.

Figure 4 shows the dramatic recovery of groundwater levels due to surface water deliveries. Water levels have fully recovered, with groundwater conditions at sustainable levels. Farmers in the Agency's service area have implemented a conjunctive use program that provides "groundwater substitution" water transfers to water short areas elsewhere in California. These transfers have generated funds enabling construction of surface water distribution facilities since the early 1990s to further expand the ability to manage surface water and groundwater in a coordinated manner.

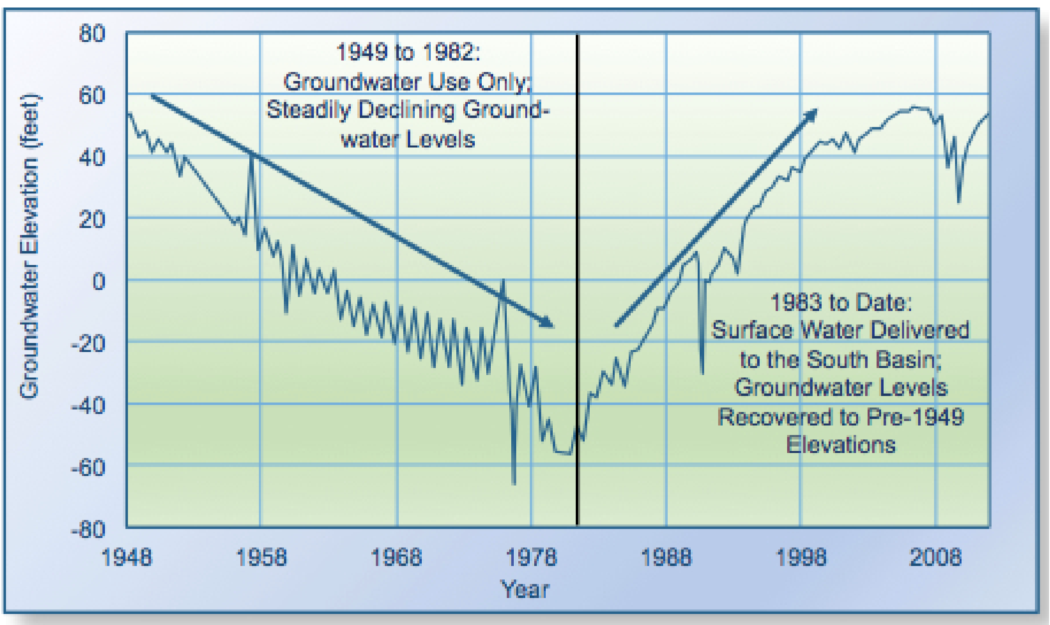

Figure 4. Water Levels in Typical South Yuba Subbasin Groundwater Well

Yolo County Flood Control and Water Conservation District (District)

The District serves surface water supplies to irrigated lands in western Yolo County, at the southern end of the Sacramento Valley west of Sacramento. These supplies supplement groundwater use throughout the region. Prior to 1977, groundwater levels had been steadily declining throughout most of the District's service area. In 1977 the District completed construction of Indian Valley Reservoir in the Cache Creek watershed. This surface storage has added an annual average of 80,000 acre-feet to the District's historic surface water supplies from Clear Lake. Since Indian Valley Reservoir began operations, groundwater levels have steadily recovered, due to the increased in-lieu recharge as well as direct recharge in the District's unlined canals made possible by increased surface water supply. In an average year, more than 25 percent of the surface water diverted from Cache Creek for irrigation goes directly to groundwater recharge. Figure 5 shows the recovery of groundwater levels since Indian Valley Reservoir began operation.

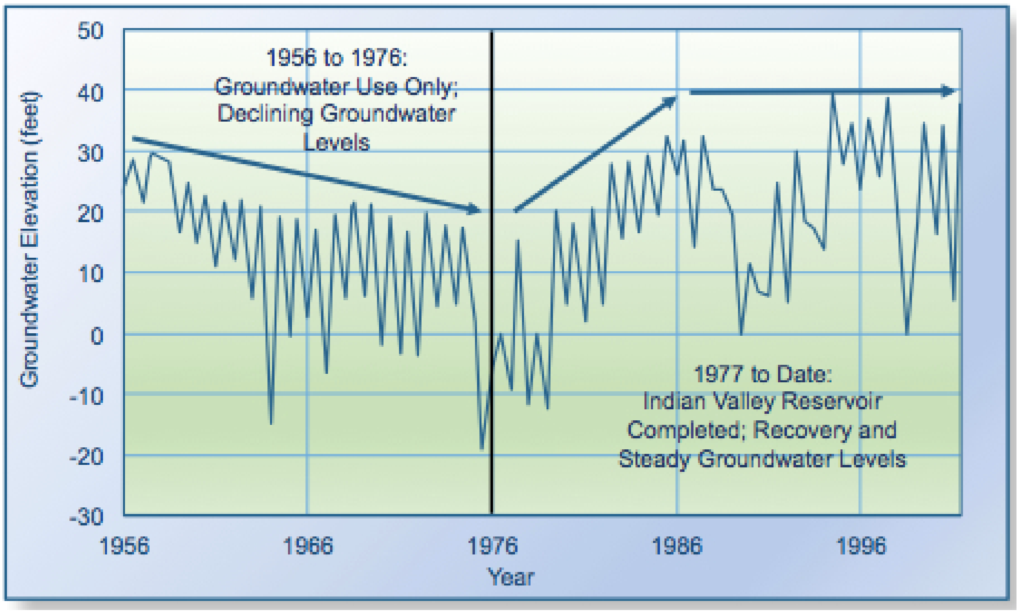

Figure 5. Water Levels in Yolo County Well Showing Recovery of Groundwater Levels

The District measures almost four hundred wells per year: once in the spring before the irrigation season, and then again in the fall after the irrigation season is finished. This monitoring program has been in place for over fifty years and serves as a valuable continuous record of groundwater level through multiple cycles of drought and high water years. This data has all been put into a publicly accessible electronic database. The District also participates in a multi-agency subsidence monitoring program that serves as an early warning of potential problems with the aquifer's ability to store water.

In addition the District has initiated a number of policies, programs and tools to enhance its ability to conjunctively manage groundwater and surface water supplies. In 2007 the District initiated a pump-incentive program, which links the District's water delivery system with the region's privately managed well network in such a way as to maximize the effectiveness of both systems. More recently, the District adopted a water rate structure that encourages surface water use in wet years and groundwater use in dry years, while helping to stabilize the District's surface water sales revenues through wet and dry cycles. The District commissioned and maintains an integrated hydrologic computer model of its surface and groundwater systems that enables evaluation of possible future changes in water supplies, cropping patterns, irrigation practices and other factors.

Northern Sacramento County

In April 2000, some 40 local interests (urban water purveyors, environmental groups and business interests) entered into the Water Forum Agreement (WFA). The WFA is a nationally recognized collaborative process that developed a plan to provide a safe and reliable water supply for planned growth in the region to 2030 and preserving the environment of the lower American River. Urban water purveyors were concerned about how they could meet their long-term water needs. Environmental conditions in the River (flow and temperature) were problematic for a number of fish species. The WFA resolved several decades of conflict concerning water supply and the environment.

One element of the WFA is effective groundwater management. In particular, a sustainable groundwater basin was needed for dry years, so that urban water suppliers could reduce their surface water diversions to provide additional water for the environmental resources on the lower American River.

The region’s water purveyors formed the Sacramento Groundwater Authority (SGA), which developed an initial groundwater management plan (GMP) in 2003 setting forth basin management objectives. The GMP has continued to be updated every few years, with the most recent update in December 2014.

The SGA has made remarkable accomplishments in the 15 years since it was formed. Conjunctive use of surface and ground water has been promoted, as has the banking of water to meet future needs. An early SGA activity was to facilitate an exchange of previously banked water to aid in environmental protection downstream in the Sacramento-San Joaquin Delta, which proved the viability of such exchanges for the region. In 2010, SGA adopted a Water Accounting Framework that included policies and procedures to promote greater conjunctive use in the region. Overall, groundwater levels in the basin have reversed a significant downward historical trend (long-term hydrograph shown in Figure 6) through the actions of SGA members to construct facilities to shift to more surface water supply in wetter years to achieve in-lieu groundwater recharge. Through its many management actions, SGA has put in place the institutional and technical means to accomplish long-term sustainable management of its groundwater basin.

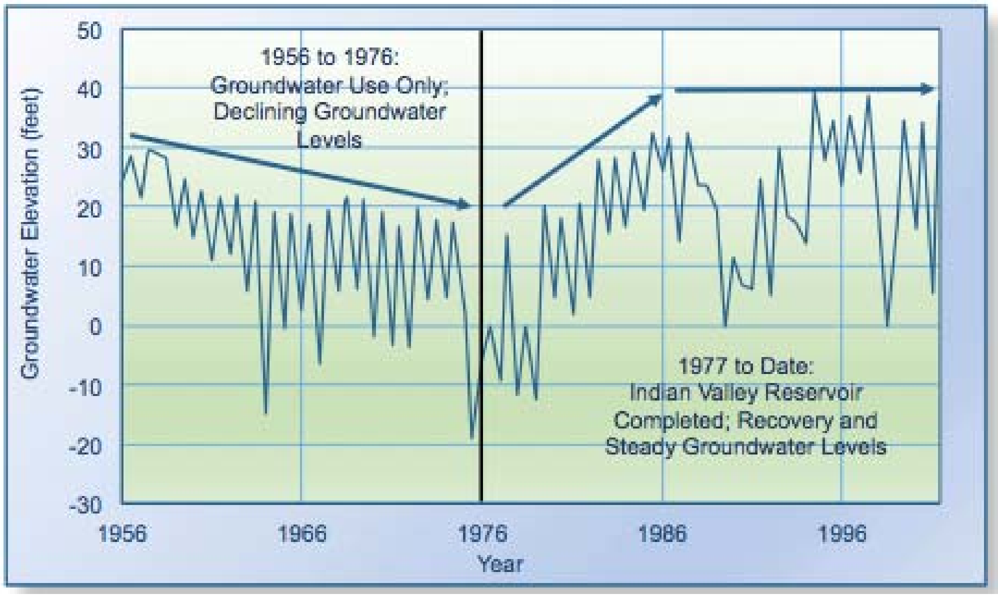

Figure 6. Sacramento Area Water Level Responses to Water Management Actions

IMPLICATIONS OF CASE STUDIES IN CONTEXT OF SUSTAINABLE GROUNDWATER MANAGEMENT FOR THE SACRAMENTO VALLEY

These successful case studies all were made possible through aggressive local leadership, the development and careful management of surface water supplies, and construction of water delivery infrastructure. Every success story recognized that augmentation of water supplies was necessary, and that active conjunctive management of surface and ground water supplies was essential.

However, the Assessment also indicates that there are long-term trends that threaten the sustainability of groundwater resources – a combination of new lands going into production that rely solely on groundwater, and what appears to be an increased frequency of drought and associated decrease in reliable surface water supplies. Whether or not the increased drought frequency over the past decade is a long-term trend, conditions are certainly drier than the historic hydrology that formed the foundation for legacy regional water projects.

Water leadership in the Sacramento Valley has shown increasing concern about these trends, and continued infrastructure and water management investments are on the table. In addition, a new state law – the 2014 Sustainable Groundwater Management Act (SGMA) – will require active engagement and management of the higher priority groundwater basins in California including all of the Sacramento Valley. SGMA implementation will take decades, but begins with the formation of “groundwater sustainability agencies” and development of “groundwater sustainability plans” that will be required to get California’s higher priority groundwater basins into balance within a few decades. The case studies presented in this paper all show the turnaround in groundwater declines and reflect different institutional approaches tailored to each service area. They provide examples of what could be accomplished, while at the same time recognizing that the addressing of institutional issues will be critical to success.

In addition, while the Sacramento Valley has abundant surface water resources in most years, that is not true for much of the rest of California. Getting the higher priority groundwater basins into balance will require “demand management”, which in some cases may require consideration of taking irrigated lands out of production in some way. This may also need to be considered in some areas of the Sacramento Valley to the extend subregions do not have access to additional surface water supplies and expansion of new agricultural lands continues. How that can be accomplished will be controversial and complex, but the possibility must be recognized. Other papers and presentations at the June 2015 Reno conference will address SGMA, including the challenges of initial implementation and implications to leadership at the local level.

CONCLUSIONS

Case studies in this paper show that with strong local leadership and substantial investment in infrastructure, recovery of groundwater to sustainable levels is possible. The Sacramento Valley Groundwater Assessment poses a question whether we are close to or at a tipping point on the sustainability of groundwater resources in certain parts of the Sacramento Valley. One conclusion in the Assessment is clear: the Sacramento Valley must take more active efforts with respect to both groundwater levels and quality for sustainable groundwater management. It is important for all water users in the Sacramento Valley to work together on this common goal. The case studies from the Assessment are success studies for several areas in the Valley, and highlight the importance of strong local leadership and significant investment in surface water facilities.

ACKNOWLEDGEMENTS

The author appreciates the support of NCWA in supporting development of the Sacramento Valley Groundwater Assessment, as well as Assessment co-authors Davids Engineering and West Yost and Associates for the collective efforts in producing this timely and useful report.

CONTINUITY VS. THE CROWD: TRADEOFFS BETWEEN CONTINUOUS AND TEMPORALLY DISCRETE HYDROLOGIC MONITORING

Jeff Davids, PE[1]
Steffen Mehl, PhD[2]
James Norris[3]

ABSTRACT

Traditional approaches to hydrologic data collection rely on permanent installations of sophisticated and relatively accurate but expensive monitoring equipment at limited numbers of sites. Consequently, the spatial coverage of the data is limited and the cost is high. Moreover, achieving adequate maintenance of the sophisticated equipment often exceeds local technical and resource capacity, and experience has shown that permanently deployed monitoring equipment is susceptible to vandalism, theft and other hazards. Rather than using expensive, vulnerable installations at a few points, SmartPhones4Water (S4W), a form of CrowdHydrology, leverages widely available mobile technology to gather hydrologic data at many sites in a manner that is highly repeatable and scalable. The tradeoff for increased spatial resolution, however, is reduced observation frequency.

As a first step towards evaluating the tradeoffs between the traditional continuous monitoring approach and emerging CrowdHydrology methods, 50 U.S. Geological Survey (USGS) streamflow gages were randomly selected from the population of roughly 350 USGS gages operated in California. Gaging station metadata and historical 15 minute flow data for the period from 10/01/07 through 12/31/14 were compiled for each of the selected gages. Historical 15 minute flow data were then used to develop daily, monthly, and yearly determinations of average, minimum, maximum, and standard deviation of streamflow, and cumulative volume for the different timesteps. These statistics were then compared to similar statistics developed from randomly selected daily spot measurements of streamflow and to statistics developed from an adaptive monitoring approach whereby weekly spot measurements were made during dry periods and daily spot measurements were made during wet periods.

Based on the results of these analyses, it appears that in certain circumstances Crowd based observations of hydrologic data can provide sufficiently reliable information for both real-time management and planning purposes. To further evaluate these methodologies, S4W is launching pilot projects in Mozambique and Nepal.

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VISUALIZATION OF BASIN-WIDE AGRICULTURAL WATER USE IN MONSOON ASIA FOR WATER FOOTPRINT INVENTORY ANALYSIS

Takao Masumoto[1]
Takeo Yoshida[2]

ABSTRACT

The visualization of agricultural water use for rice cultivation involves the compilation and quantification of irrigation inputs and drainage outputs by means of a hydrological model that can be applied for basin-wide evaluation of paddy-dominated agriculture. Here, we describe the application of the model DWCM-AgWU for this purpose, which is quite unique in that it demonstrates the interaction of water cycles with anthropogenic practices in agricultural water use and the recirculation use of water through returning flows in a basin scale. The highlights of the analysis are as follows: (i) Water availability is calculated for where land management practices (e.g., forestry, agriculture, wetland conservation) modify water availability (e.g., by regulating river flows and recharging groundwater); (ii) The analysis is conducted at various scales ranging drainage basins and resolutions. The analysis can be applied to calculate water footprint inventory through the following ways: The water footprint inventory for rice cultivation in paddy areas is carried out at the basin scale. Each element of water availability relevant to rice cultivation and its water footprint is calculated by DWCM-AgWU. The model estimates planting area of paddies, intake amount, soil moisture, and other related agricultural water use variables for any location (arbitrary cells) in the basin, which results in an estimate of the water footprint for assessing the impacts of human interactions on basin-wide water circulation and food production. We present an example analysis from Japan. The procedure is applicable to any river basin in monsoon Asia, even where intensive irrigation and various other types of agricultural water use are employed.

INTRODUCTION

Water is an essential natural and renewable resource. The issue of water use and management has become increasingly central to the global sustainability issue. This increased interest has been driven by growing water demand, increasing water scarcity in many areas. This drives the need for a better understanding of water use as a basis for water management at local, regional and global levels. One of the techniques being developed for this purpose is the water footprint research. Various methodologies for assessing water footprints exist, and currently these methodologies emphasize different aspects of water use to report water footprint results. As an aspect of agricultural water use in Monsoon Asia, however, it should be clearly described that a water footprint

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covers positive aspects such as increase of water availability. In addition, it should be understood that this definition refers to the fact that substantial availability increases by management being carried out in the field of agriculture and forestry not only the field of industry where the production process is manageable.

On the other hand, appropriate management of forests and rice paddy fields together with conservation of wetlands result in enhancing water availability by leveling off river flows, recharging groundwater and their returning to rivers. Those functions are evaluated as the multifunctional roles (multifunctionality) of agricultural water use (Masumoto T. *et al.*, 2008). In addition, paddy fields generally have a water storage function so that they can retain part of flooding water. The capacity of the function would be assessed as a flood reducing effect (Masumoto T. *et al.*, 2006). The function can mitigate flood damage in downstream.

This study discusses a quantitative evaluation method to calculate water footprint inventory by describing the application of a hydrological model, which demonstrates the interaction of water cycles with anthropogenic practices in agricultural water use and the recirculation use of water through returning flows in a basin scale. In addition, water availability is quantitatively calculated for where land management practices, such as forestry, agriculture, wetland conservation and so on, modify water availability by regulating river flows and recharging groundwater.

METHOD TO VISUALIZE WATER CIRCULATION PROCESSES INCORPORATING AGRICULTURAL WATER USE

How to Describe Positive Aspects of Agriculture?

In rice paddies, some irrigation water infiltrates into underground and arrives at the groundwater table (**Figure 1**), so that paddies raise the groundwater level and recharge groundwater resources. The volume of groundwater recharges by rice irrigation has been calculated by assuming that this volume (m^3) equals to the cross-multiplication of water requirement rate (m/day) by the duration of irrigation (day), the number of irrigation days (day) and paddy rice planted area (m^2). However, this estimation is too rough to be used for our purpose. What is more, return ratio of the irrigated water has not been estimated due to the complexity of its mechanism, either, which will be explained later in this paper.

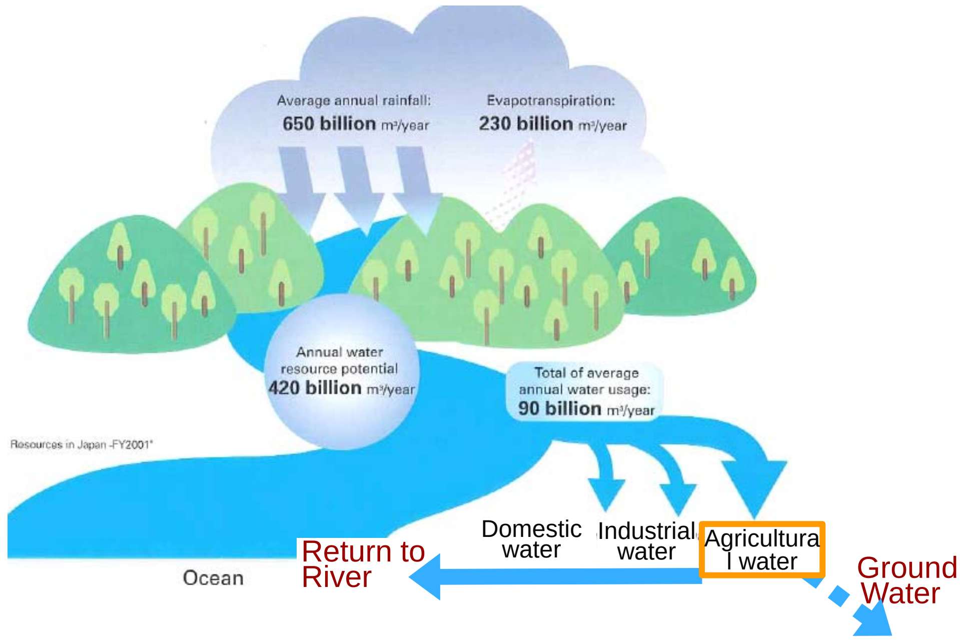


Figure 1. Water circulation in a basin

Water footprint has been analyzed in the Project of "Visualization of Agricultural and Forestry Water Resources" (2013—2015) under the Ministry of Agriculture, Forestry and fisheries (MAFF) of Japan. Related researches were found in the activities of virtual water (VW) (Qadir M. *et al.*, 2003) or green and blue water discussion (Rost S. *et al.*, 2008), but our proposal was that groundwater recharge and return flow were evaluated by a hydrological model, especially by the Distributed Water Circulation Model incorporating Agricultural Water Use (DWCM-AgWU) to assess anthropogenic water use (agriculture itself) and climate change (**Figure 2**).

DWCM-AgWU Model and Its Verification

Features of water resources in Monsoon Asia are characterized as the coexistence of dry and wet seasons (including extremes), dominant usage of water by rice paddy agriculture (See **Figure 1**), the existence of various irrigation types and so on. Therefore, it is hard to schematize the mechanism in paddy fields and rice crop dominant areas. Those characteristics are pictured out in the examples, taking the Mekong River Basin as a large basin of uncontrolled water use for only 9% irrigation and the Seki River Basin, Japan, as fully irrigated and well-developed management of agricultural water use, for examples. Therefore, modeling of agricultural water use was carried out as the DWCM-AgWU [STEP 1], and this model was applied to estimate i) groundwater recharge, ii) return flow ratio as a water footprint inventory analysis [STEP 2].

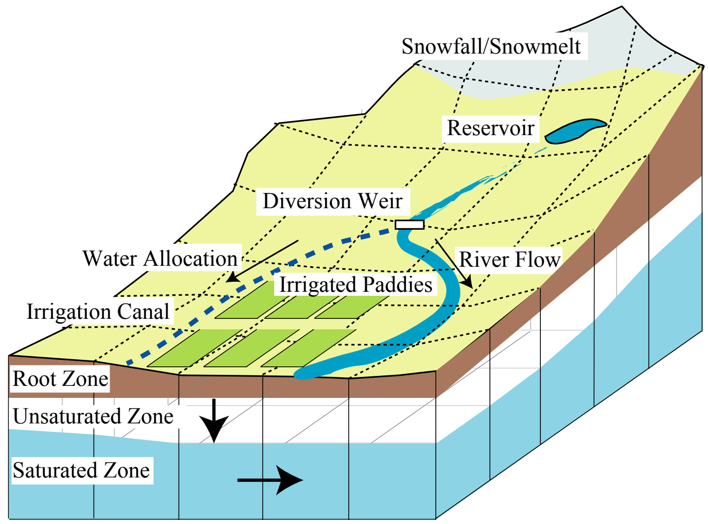


Figure 2. Depiction of basin-wide processes

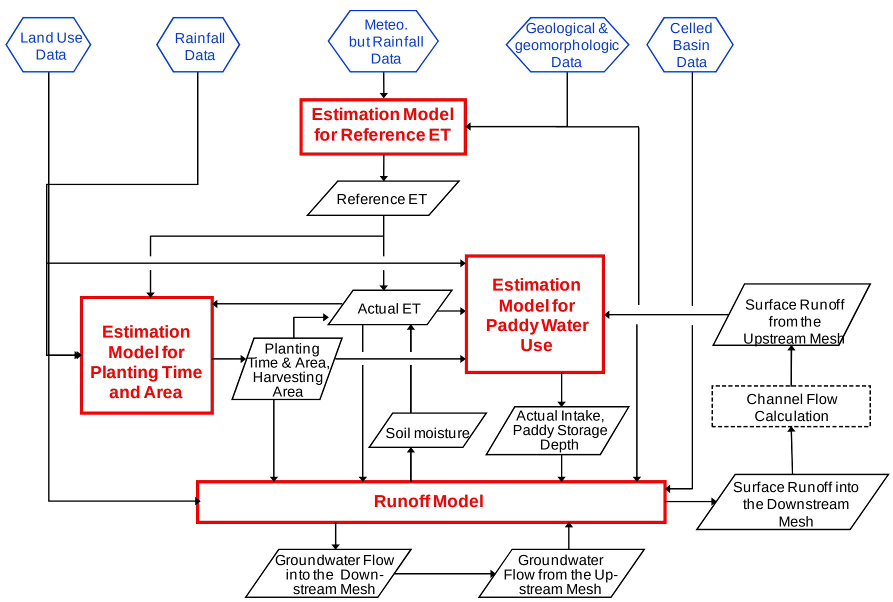


Figure 3. Calculation algorism of the distributed water circulation model

The DWCM-AgWU incorporates an Evapotranspiration Estimation Model, a Cropping Time and Acreage Model for paddy rice, a Paddy Field Water Use Model, and a Runoff Model to express water circulation (**Figures 2 and 3**). The model was developed on a 0.1° (~10 km) cell by Masumoto *et al.* (2009), and verified by on the basis of flow observations and evapotranspiration measurements in the Mekong River basin (800,000 km^2 in area) at five locations along the Mekong River and, and further modified by Yoshida *et al.* (2012) applying to an irrigation-dominated river basin, Seki River basin on a 0.01° (~1 km) mesh, in Japan. The model can estimate variables including river flow, farmland water use in areas of paddy rice, volumes of water intake, and soil moisture content at any desired time and place within a basin.

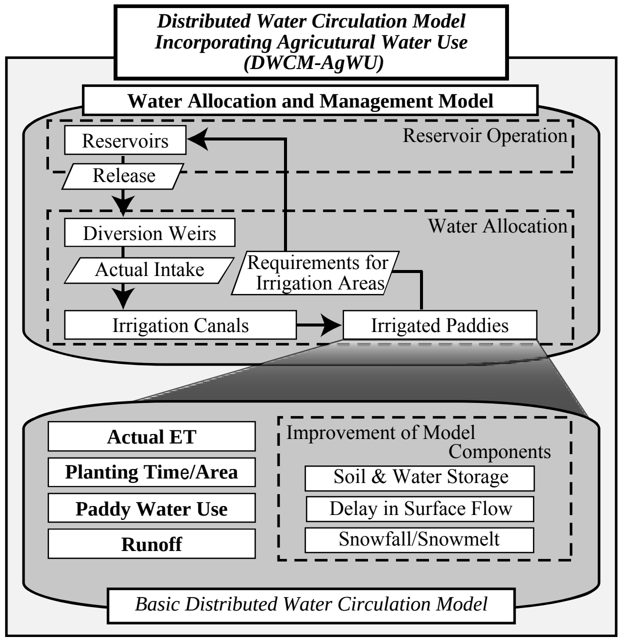


Figure 4. Components of the water footprint inventory analysis

The DWCM-AgWU as a basic basin-wide runoff model was then modified by combining reservoir management processes to compare river discharges (available water) at division weirs and water requirement in irrigated paddies, then to release water for irrigation. What is more, it was coupled with water allocation and delivery management processes (anthropogenic activities) in irrigated paddies to decide intake, water allocation, infiltration, drainage and so on (Yoshida, T., 2015), shown in **Figure 4**.

It can also be used to assess or predict the impact of various human activities on basin water circulation. The model is applicable for all regions and basins in monsoonal Asia, and for other similar and/or unique areas (Kudo, R. *et al.*, 2015; Vongphet, J. *et al.*, 2014). The input data required by the model are shown in **Figure 3**.

WATER FOOTPRINT INBVENTORY ANALYSIS OF UNIT PROCESSES

Description of Water Availability — Paddy Water Use in Monsoon Asia

This proposed example is related to rice cultivation, which would be a suitable demonstration of interaction with and moderation of natural cycles through recirculation use of water (**Figure 2**). The highlights of the example are as follows:

1) The example is a case study of a water footprint assessment that utilizes existing knowledge, the hydrological model, such as the DWCM-AgWU mentioned above, to analyze a water footprint inventory of unit processes (see Figure 1 of ISO 14046, 2014).
2) The calculation process estimates water availability for a case in which land management practices (e.g. forestry, agriculture, conservation of wetlands) can modify water availability (e.g. by regulating river flows and recharging groundwater).

3) Although water availability is compared across distant locations and regions, the inventory analysis is conducted at scales and resolutions suitable for a drainage basin, a catchment, or even a sub-catchment.

Goal and Scope Definition

Although previous ISO calculation examples related to rice cultivation emphasized the importance of regional characteristics and required detailed descriptions of water usage and circulation, we applied the water use model to a single process, rice cultivation, to explain complicated processes on a basin-wide scale. The target region is one of the typical irrigation-dominated types of river basins in Japan, where the typical moderate rainfall is suitable for rice cultivation.

Water Footprint Inventory

This water footprint assessment involves compilation and quantification of inputs and outputs related to water for unit processes of irrigation, as defined for the single process of rice cultivation. The unit processes are quantified by utilizing a hydrological model, such as DWCM-AgWU, at the scale of drainage basins. In this example, water footprint inventory analysis is carried out as the indicator of the impact category "water availability". It typically applies to situations such as a basin-wide evaluation of paddy-dominated agricultural areas.

Elementary Flows and Water Circulation

In the approach of the water footprint inventory method, a single process in agricultural areas receives rainfall and irrigation water at agricultural facilities (such as diversion weirs in **Figure 2**) as inputs, and evapotranspiration and infiltration into groundwater are the outputs. The remaining water not used directly by the rice crop returns to river systems at several points (**Figure 5 (b)**). The elementary flows in an irrigation region are the volumes of the freshwater input, including those from residual areas connected to an irrigation region, and the freshwater output, at the locations in the water body from which the input water is withdrawn and to which the output water is released.

Only freshwater that is usable for irrigation is considered as water input or water output. Furthermore, all input water is withdrawn from multiple locations of the process and all output water is released to multiple locations of the process. Part of the water output to groundwater gradually returns to the river system or sometimes is utilized as a source of drinking water by city dwellers. In paddy areas, the sources of freshwater are a mix of rainwater and irrigation water. In both cases, various types of water use exist.

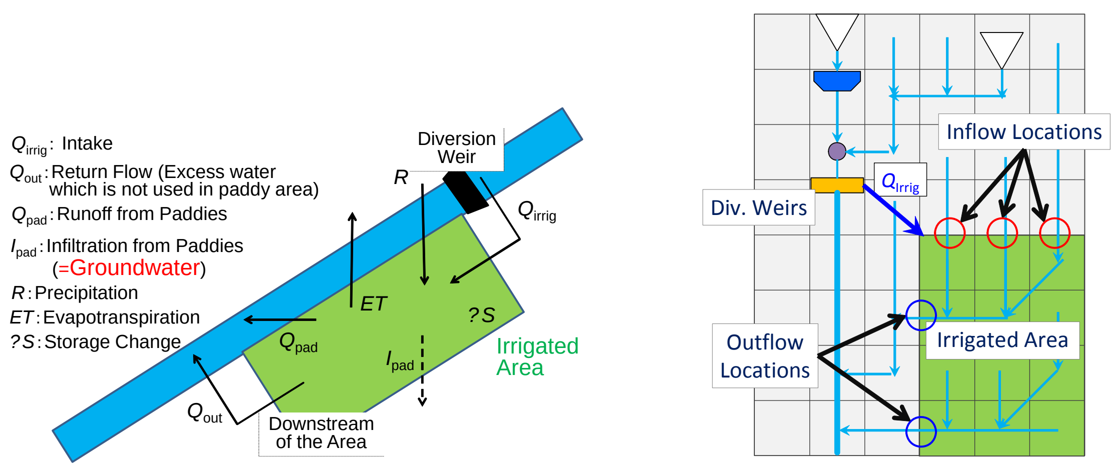
Calculation of Water Footprint Inventory

For water footprint inventory analyses, the calculation procedure as shown in **Figure 4** is applied. The definition and/or calculation procedure of water footprint inventory proposed in water availability are as follows:

1) The water footprint inventory of the unit process for rice cultivation in paddy areas is carried out at the basin scale (See **Figure 2**).
2) Each element of water availability relevant to rice cultivation and its water footprint is calculated by a model, such as using DWCM-AgWU, which consists of a Water Allocation and Management model, an Actual ET model, a Planting Time/Area model (for rice phenology), a Paddy Water Use model and a Runoff model (**Figures 3 and 4**).
3) Agricultural water use for paddies is divided into rain-fed and irrigated paddies and the respective water footprint inventories are estimated.
4) Agricultural water use is depicted as the combination of these paddy categories: irrigation dominates water use in East Asian regions such as Japan whereas rainwater dominates water use in most of Southeast Asia. In areas with two or three crops a year, paddies are classified as rain-fed in the rainy season and irrigated in the dry season.

The procedure is applicable to any river basin in monsoon Asia, despite intensive irrigation and various other types of agricultural water use being employed. The results are then summed across the basin. An example for one region of a basin is shown in **Table 1** and expressed in the units, m^3 H_2Oe/yield of 1kg brown rice, or m^3 H_2Oe /1ha /irrigation period, for example.

<u>Calculation Method of Positive Functions in Paddy Irrigation</u>



(a) Water balance (groundwater and return flow) (b) Inflows and outflows in an irrigated area

Figure 5. Schematics of the calculation of river return flow ratio

A water footprint alone is insufficient to be used to describe the overall potential environmental impacts of processes. So it is acknowledged that the water footprint term is also used in other contexts than the life cycle assessment (LCA) context. The water footprint study for agricultural water use can be assessed as a part of a more comprehensive environmental assessment, such as multifunctionality of agriculture. Here it is explained by using groundwater recharge and river return flow functions by paddies for examples.

In a water balance analysis in an irrigated area, infiltration from paddies (recharge into groundwater) is estimated in the following equation (**Figure 5 (a)**):

$$Q_{irrig} + R = Q_{out} + Q_{pad} + I_{pad} + ET + \Delta S \qquad (1)$$

in which Q_{irrig} is intake, Q_{out} is return flow (Excess water which is not used in paddy area), Q_{pad} is runoff from paddies, I_{pad} is infiltration from paddies (=groundwater recharge), R is precipitation, ET is evapotranspiration, and ΔS is storage change, in which $\Delta S = 0$ is assumed in many cases.

Then, the positive water footprint is estimated in the following manner.

$$V_{gr} = q_{ground} \times D_{irrig} \times A_{paddy} \qquad (2)$$

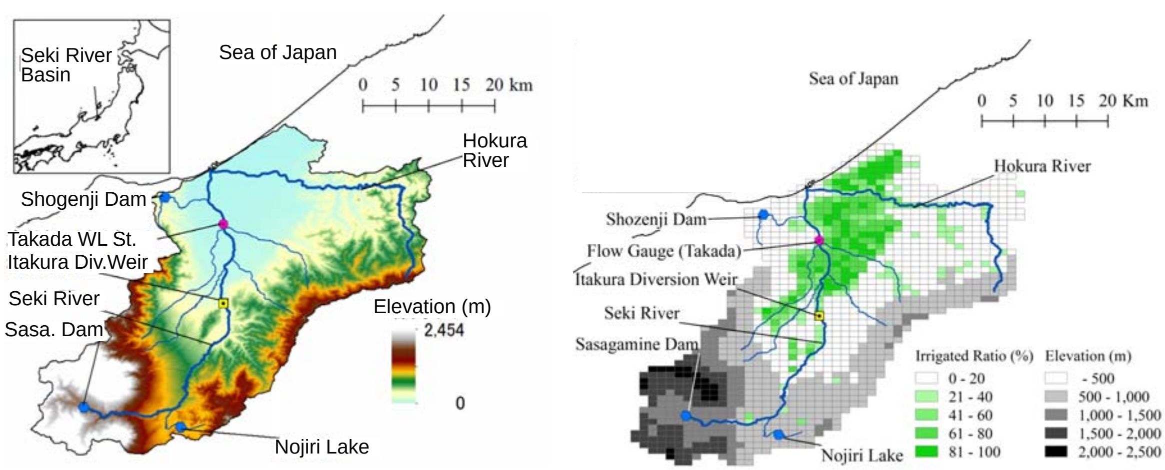
in which V_{gr} is volume of groundwater recharge (m^3), q_{ground} is infiltration amount (m/day), D_{irrig} is duration of irrigation (day), A_{paddy} is paddy rice planted area (m^2).

On the other hand, river return ratio is calculated as:

$$f_{return} = \sum_{t=1}^{n} [Q_{return} /(Q_{irrig} /(Q_{irrig} + R - Q_{res})] \qquad (3)$$

in which f_{return} is return flow ratio, Q_{irrig} is intake at division weirs (m^3), R is precipitation (m3), Q_{res} is inflow from residual areas at multiple inflow locations (m^3), and Q_{return} is return flow at multiple outflow locations (m^3).

As is shown in **Figure 5 (b)**, the information and/or values for multiple locations and cells are necessary, but it is not easy to obtain those in observations. However, once the unit processes in agricultural water use are visualized in the model as DWCM-AgWU, the obtained estimates by the model are utilized in the above estimation, or these values are tabulated in LCA database.



(a) Location (b) Paddy ration in cells

Figure 6. Details of the study basin

RESULTS AND DISCUSSIONS

The Target Basin

The Seki River basin in central Japan was selected for a target basin for the model application. It is 64 km long, and its catchment area is 1,140 km^2. The land cover is dominantly forest (79%), but 17% of the land area of the catchment is agricultural land, mainly rice paddies. The Seki River flows from the Myoko Mountains (highest peak, about 2,400m) (**Figure 6 (a)**). The climate of the basin is humid, typical of the Japan Sea area, and snowfall is heavy in winter. Average annual precipitation is more than 3,000 mm, over half of which falls as snow in winter. The total irrigated area of the basin is approximately 9,000 ha, and it is mostly used for rice paddies. There are two major irrigation systems on the eastern side of the Seki River. There are key irrigation facilities, such as Sasagamine dam ($9.2 \times 10^6 m^3$), and the Itakura diversion weir. River discharge are observed at Takada flow gauge station (**Figure 6 (b)**). There are three major irrigation blocks (areas), for which water is diverted at the Itakura and two other diversion weirs, respectively (**Figure 8**).

Input Parameters and Model Verification

For unit processes, input parameters are land use data, meteorological data, geological and geomorphological data, and celled basin data. The model estimates planting area of paddies, intake amount, soil moisture, and other related agricultural water use variables for arbitrary locations in the basin. The method is effective and reliable for assessing the impacts of human interactions and climate change on basin-wide water circulation and food production. The output closely fits the observed values, such as discharges of rivers and evapotranspiration; thus, it can provide reliable data in the absence of measured data and un-measured data for its complicity process.

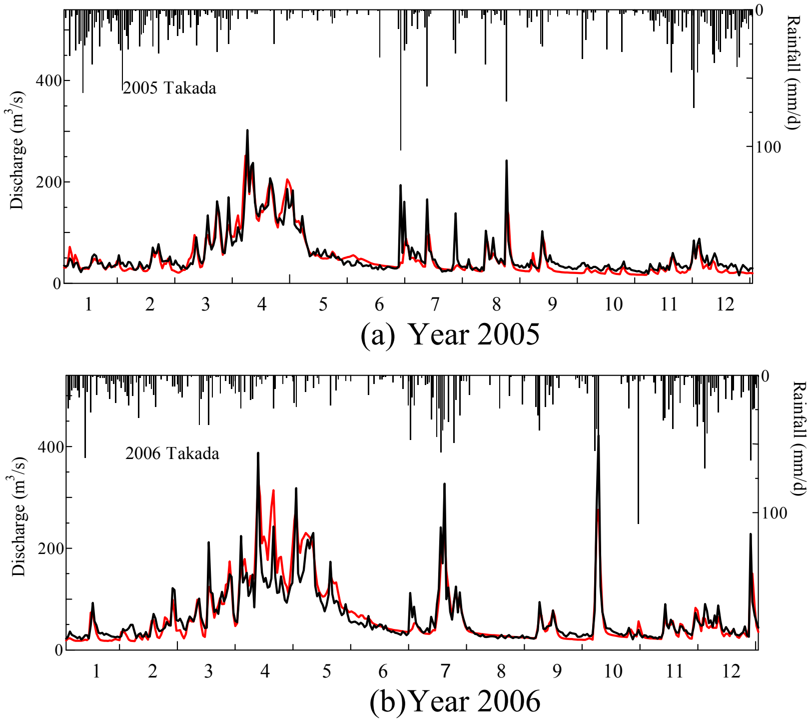


Figure 7. Verification of the model
(Comparison of the observed and calculated discharges at the Takada Station)

In actuality, model performance was evaluated by comparing the calculated and observed actual discharges for the Seki River Basin during the period from 1976 to 2008. The hydrographs at Takada for 2005 and 2006 are shown in **Figure 7**. The relative error between these discharges was 25%.

Calculated Results

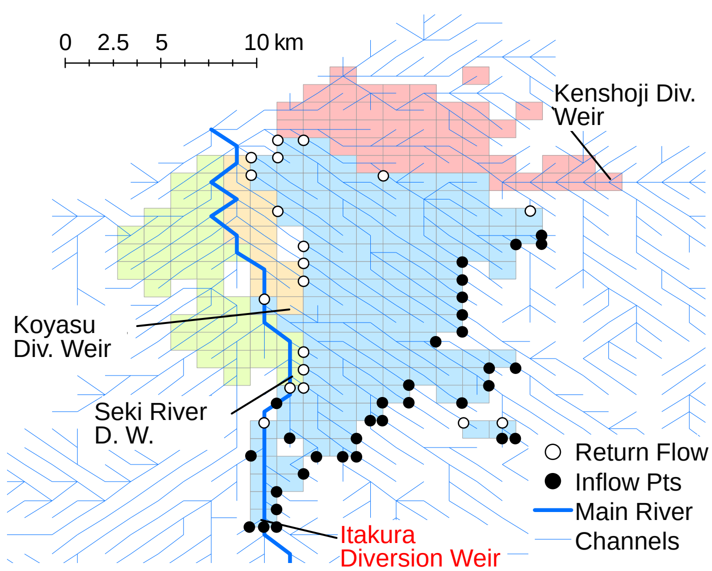


Figure 8. Inflow and outflow locations for a target irrigated area

Our example case involves the averaged results of daily calculations for 33 years, the single process of "rice cultivation" involves flows of rainfall (888 mm during periods of irrigation) and irrigation water (957 mm in irrigation periods) during the cropping period (**Table 1**). Other elements determined by DWCM-AgWU are evapotranspiration from agricultural areas (510 mm in irrigation periods) and infiltration into groundwater (623 mm in irrigation periods). At the basin scale, by using the water allocation and management model (Yoshida, T. *et al.*, 2012), the ratio of irrigation water to total available water (rainfall plus irrigation water) was 0.53 and the return ratio of irrigation water into the river system was 0.70, which shows that most of the irrigation water was used to maintain aquatic environments in the area and to regulate river flows.

The production of brown rice in the region was 5.39 ton ha^{-1}. Although the apparent withdrawal of water for irrigation was 9,570 ton ha^{-1} (1,780 H_2Oe kg^{-1} brown rice), the real consumption was 5,100 m^3 ha^{-1} (946 l H_2Oe kg^{-1} brown rice), or 11,300 ton ha^{-1} (2,100 l H_2Oe kg^{-1} brown rice). In addition, the groundwater recharge function of rice paddies in this particular example is 1,160 l H_2Oe kg^{-1} at the basin level. This means that rice production results in a burden on freshwater resources equivalent to 2,100 litters of direct water use at the global average water availability index.

The major factor contributing to the water consumption in this example is irrigation. The water availability footprint of rice cultivation is high because irrigation occurs in addition to rainfall input. It is important to note that agricultural water, especially for paddy cultivation, should be evaluated at basin scales and that the term of planting time/area should encompass the period when water stress is low; and that agricultural water use and agriculture serve several functions such as recycling of water for paddy cultivation, groundwater recharge by rice irrigation, and reuse by river systems instead of being lost from the basin.

Table 1. Water footprint inventory analysis for 33 years (1976–2008) in the "Seki" River Basin, Japan

Items	Unit Processes, ton/kg yield**	Ratio of Irrigation Water to Potential Water Availability ($R + Q_{irrig}$)	River Return Ratio ([Return to Rivers] /[Irrigated Water])*
Rainfall (R)	1.649		
Irrigation water (Q_{irrig})	1.776 (4.593)		
Inflows from residual areas (Q_{res})	(6.491)	0.52 (0.74)	0.70
Returns into rivers (Q_{return})	(11.410)		
Infiltration	1.158		
Evapotranspiration	0.946		

(*): The river return ratio is the combination of daily inputs and outputs considering Q_{res} (37 locations) and Q_{return} (23 locations) at plural points obtained only by the model calculation.
(**): Values in parentheses are mean gross estimates rather than net values. The estimation was carried out in the 76.3 km^2 irrigated paddy region.

CONCLUSIONS

Calculation processes of water footprint inventory are shown as an example of agricultural water use for unit processes. Highlights found in the application were as follows: i) the effective usage of the existing knowledge/tool, such as a hydrological model, ii) the modification of the definition of water availability as adding positive aspects of agricultural water use, and iii) the importance of a drainage basin-scale analysis. In addition, actual estimation procedure for the water footprint of agricultural water use was summarized as: 1) the target is rice cultivation in paddy areas at the basin scale; 2) Each element of unit processes is calculated by a model like DWCM-AgWU, which consists of 5 sub-models; 3) The estimation for respective water footprint of rain-fed and irrigated paddies is possible; 4) Seasonal combination of water use in two/three crops cultivation, such as rain-fed in the rainy season and irrigated in the dry season is available; 5) The procedure of this water footprint inventory is expanded to the examination of multifunctional roles of agricultural water use, such as groundwater recharge, river return flow from paddies.

As summaries and further issues, the following points were picked out. First, the hydrological model estimates agricultural water use variables for arbitrary locations and times in the basin. The major factor of the water consumption in an example is irrigation. The water availability footprint of rice cultivation is quite high. In addition, secondly, we have to notice that agricultural water use, especially for paddy cultivation, should be evaluated at basin scales in that the term of planting time/area should encompass the period when water stress is low and in that agriculture serves several functions such as recycling of water, groundwater recharge, and reuse by river systems, and so on.

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ESTIMATION OF CLIMATE CHANGE IMPACTS ON FLOODING IN LOW-LYING PADDY AREAS IN JAPAN

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ABSTRACT

An increase in flood risk, especially in low-lying areas, is a predicted consequence of global climate change. Immediate measures such as increasing the drainage capacity are needed to minimize the damage caused by this more-frequent flooding.

In the present study, we assessed the flood risks for rivers and paddy fields in Japan's Kaga three-lagoon basin, which has two lagoons and associated low-lying paddy areas. We applied a flood analysis model, which can calculate water levels in the rivers and paddies, to the study area to estimate the future risks. We used a rainfall simulation method called the "diurnal rainfall pattern generator", which can generate short-time-step temporal rainfall patterns, to generate the input data. The generator predicted the 3-day total rainfall for 10 return periods (ranging from 2 to 200 years), and for each amount, generated 300 hyetograph patterns. These data served as inputs for the flood model.

Our analysis focused on the frequency distribution of peak water levels that exceeded an allowable flood level at monitoring points. The result was a series of curves for the relationship between rainfall and flood risk. Furthermore, we estimated the mean duration of flooding deeper than 0.3 m for the paddies. We found that the risk increased with increasing rainfall, but also depended on the hyetograph for the input rainfall, including both the rainfall amount and its temporal pattern. These results will help managers to predict and mitigate the impact of climate change on flooding.

INTRODUCTION

As a result of climate change, the intensity and frequency of heavy rainfall events are predicted to increase in many regions. Large-scale rainfall events often trigger flooding, especially in low-lying areas. In monsoon Asia, paddy fields are important for food production, and have expanded greatly in low-lying areas, where they are vulnerable to flooding. (Although paddy crops are flooded during at least part of the growing season, the water depth must be controlled to avoid drowning the plants.) In Japan, managers try to prevent damage from flooding by planning the capacity of drainage infrastructure such as canals and pumps based on an analysis of drainage needs for a certain design rainfall (e.g., the 3-day rainfall based on a 10-year return period). However, the design rainfall used in this planning has not been revised for several decades, and changes in rainfall patterns associated with recent and future climate change are not reflected in the current guidelines. If rainfall amount and intensity increase, as predicted, then immediate measures are needed to support planning for how to minimize the damage caused by

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these events. Paddy fields also provide an important water storage function, and can retain part of any flood. Their capacity in this function can be described as their "flood-reduction effect". This function can mitigate or prevent flood damage in downstream regions, and might therefore be an important countermeasure against more frequent flooding. To support this function, it is necessary to provide a detailed description of the potential flooding by means of flood analysis, because rice plants are cultivated in these paddies and must be protected. One result of flood analysis is a hyetograph for the input rainfall, at hourly or longer intervals, since the temporal pattern can vary greatly between events even if the total amount of rainfall is equal, leading to different flood risks. Therefore, it is important to describe the patterns of heavy rainfall in any flood risk assessment. Ideally, data on heavy rainfall events is extracted from long-term meteorological data observed near a study area. Unfortunately, it can be difficult to collect a large enough sample size, because rainfalls that cause flood disasters are low-frequency events. In addition, even if enough samples can be obtained at a daily resolution, data with hourly (or shorter) resolution is rarely available. In addition, many meteorological stations have only been collecting short-time rainfall data, which is not long enough to provide detailed information on extreme events. To provide the data required for planning, rainfall simulations can be used to generate many patterns of rainfall data. The generated data, which considers the key characteristics of the observed rainfall (i.e., both the amount and the temporal pattern), are useful input data in various kinds of study, including flood analysis. Many researchers have studied rainfall generation (e.g., Woolhiser and Osborn, 1985; Hershenhorn and Woolhiser, 1987), and in our previous research (Minakawa *et*. *al*., 2014a), we proposed a rainfall simulation method that we called the "diurnal rainfall pattern generator" that could generate short-time-step patterns of the rainfall amount and temporal pattern. The results produced by the generator can be used to estimate the risk of flooding for a given rainfall pattern.

In this paper, we discuss a quantitative evaluation method for detecting the relationship between the risk of flood damage and heavy rainfall events. We used the diurnal rainfall pattern generator to assess the effects on the flood risk in terms of both the amount of rainfall and its temporal pattern. In addition, we used this relationship to predict the flood damage in paddy fields.

THE STUDY AREA

The Kaga three-lagoon basin includes low-lying paddy areas that are vulnerable to flooding as a result of increasing rainfall and rainfall intensity (**Figure 1**). The basin is located in a low-lying area. The catchment has a total area of about 250 km^2. It is divided into upland areas (in the upstream parts, mostly forested) and flooded areas (in the downstream parts). The lower reaches of the basin are covered by paddy areas and by two lagoons (Shibayama and Kiba). In this basin, the drainage system is topographically divided into two networks: one passes through the Shibayama Lagoon (the Shibayama Lagoon network), and the other passes through the Kiba Lagoon (the Kiba Lagoon network). Low-lying paddy fields cover 2600 ha in the Shibayama network and 1350 ha in the Kiba network. Both networks have drainage rivers that flow from the upland area in the south into the low-lying areas in the north: the Youkaichi River (catchment area 5.0

km^2) and the Iburihashi River (88.9 km^2) in the Shibayama network, and the Hiyou River (12.0 km^2) in the Kiba network. These networks are usually separated from each other by a sluice-gate, but in an emergency (e.g., during heavy rainfall events) they can be operated cooperatively to manage water levels. In the present study, we evaluated the flood risks separately in the two networks

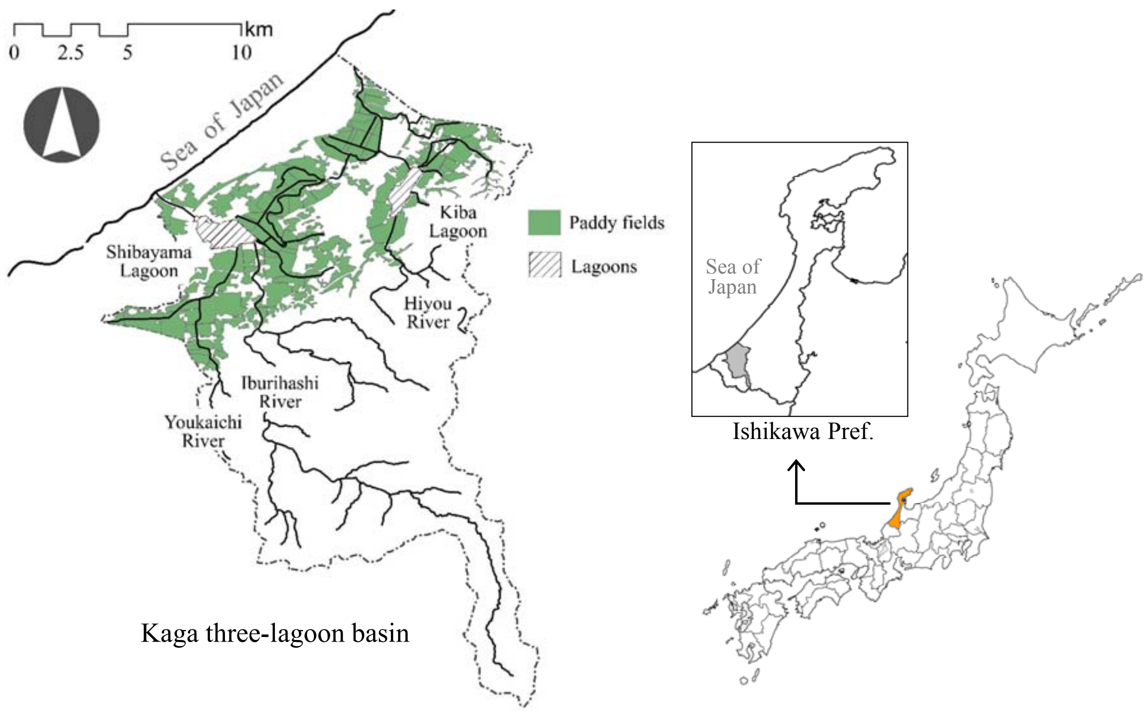


Figure 1. Outline of the study area

DEVELOPMENT OF THE FLOOD ANALYSIS MODEL

We developed a flood analysis model for the study area to estimate flood risks in the channels and paddy fields. The model consisted of a kinematic-wave runoff model, which was applied to the uplands, and a drainage analysis model, which was applied to the flooded area. We applied the model concurrently to the Shibayama and Kiba lagoon networks.

Kinematic-wave model

We applied this model to calculate the discharge from upland areas. The model is based on the following momentum and continuity equations for downslope flow:

$$h = kg^p \tag{1}$$

$$\frac{\partial h}{\partial t} + \frac{\partial q}{\partial x} = r_e \tag{2}$$

where h is the water depth (m), t is time step, q is the unit discharge from the slope, r_e is the effective rainfall, and k and p are parameters. In this study, we used $p = 0.06$ and $k = (N\,s^{0.5})^p$, where s is the slope, and N is the equivalent roughness used in the kinematic-wave method. N is mostly determined by the land use in each part of the study area.
The rivers and the basin were divided into small basins along each river's tributaries by using topographic maps (1/25,000). The area and slope in each small basin were calculated using a geographical information system (GIS) software, and the elevation data were determined using a digital elevation model (DEM) with 50-m pixel resolution. The results of these calculations were input into the drainage model as the flow boundary conditions from the upstream side of the basin.

Drainage Analysis Model

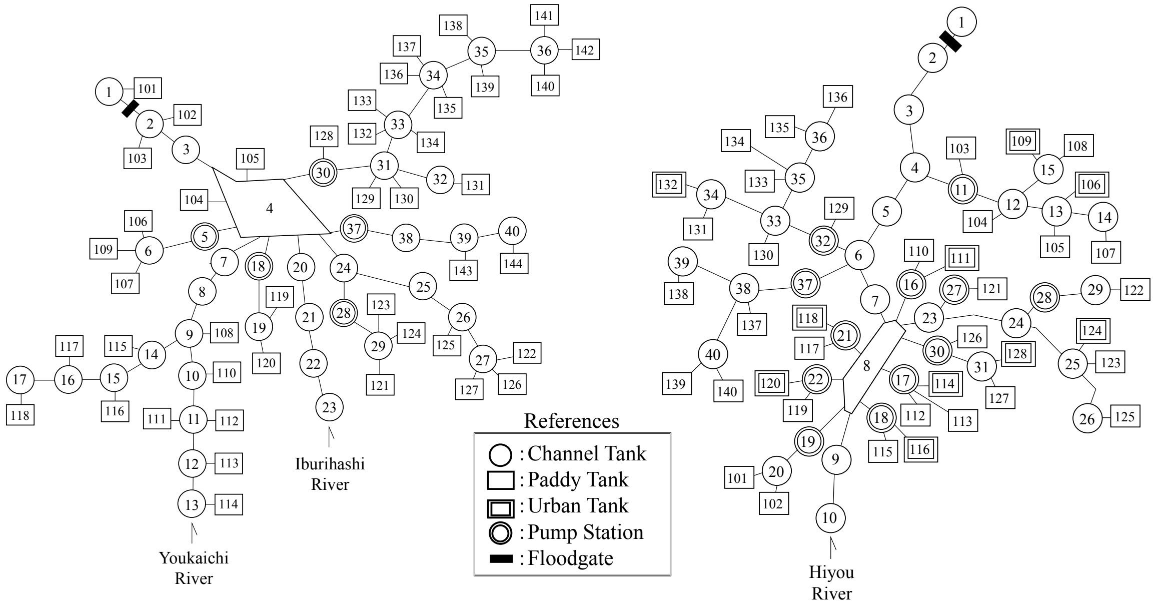
In Japan, the land in low-lying areas is mainly used for paddy fields. To analyze the outflow characteristics of the low-lying areas, such as the storage effect of the paddy fields, it is necessary to develop a drainage model that can manage water movement between the channels and the paddy fields. We chose a diffusive tank model (Hayase and Kadoya, 1993), which is a simplified runoff and drainage model for analyzing channel flow and flooding in paddies. The model was constructed by connecting the channels with the paddies (here, represented as "channel tanks" and "paddy tanks", respectively), and estimating the water level and discharge for every channel tank and paddy tank. The paddy and channel tanks were connected by weirs, and the flows between them were expressed as non-uniform flows. The continuity and momentum equations for the channel tanks are given by equations 3 and 4, respectively:

$$\frac{W_j^{n+1}+W_j^n}{2}\frac{H_j^{n+1}-H_j^n}{\Delta t}=\frac{\left(Q_i^{n+1}+Q_i^n\right)-\left(Q_j^{n+1}+Q_j^n\right)}{2} \tag{3}$$

$$Q_j=\frac{A_j R_j^{2/3}}{N_j\sqrt{X_j}}\frac{H_j-H_k}{\left|H_j-H_k\right|} \tag{4}$$

where W_j and H_j are the surface area and water level, respectively, in tank j at time step n; n is the time step; Δt is the time between time steps n and n+1; Q_i and Q_j are the inflow and outflow, respectively, for tank j; A_j is the area of tank j; R_j is the hydraulic radius of tank j; and X_j is distance between tank j and k. The momentum equation for water flowing between the channel and paddy tanks is given by the weir equation.
Figure 2 illustrates the drainage analysis models for the two lagoon networks. We created the channel tanks by dividing the rivers and drainage canals into several parts (lengths of the tanks ranged from 500 to 1500 m). Lagoons were treated as channel tanks with large surface areas, so that tank no. 4 in Figure 2(a) corresponds to the Shibayama Lagoon and tank no. 8 in Figure 2(b) corresponds to the Kiba Lagoon. As a result, we obtained 34 channel tanks and 44 paddy tanks for the Shibayama lagoon network, and 35 channel tanks and 40 paddy tanks (including 10 urban tanks, which don't have water storage function. Input rainfall into the tanks is rapidly runoff to attached channel.) for the Kiba lagoon network. Moreover, drainage pump stations and floodgates were included in each network. In the model, they were automatically switched to ON/OFF or OPEN/CLOSED

in accordance with each operational rule as part of a system of controlling water levels.



(a) Shibayama lagoon network (b) Kiba lagoon network

Figure 2. A diagram of the diffusive tank model in each network

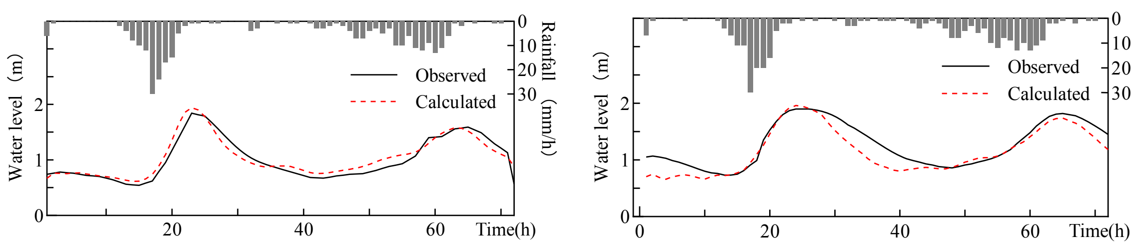
The tanks were numbered sequentially from downstream to upstream. Discharge data calculated in the uplands were used as inputs for tanks no. 13 and 23 in the Shibayama network and tank no. 10 in the Kiba network, and represented the upper boundary conditions for discharge.

Flood Routing and Verification of the Models

We used data from a heavy rainfall event (about 300 mm) that occurred from 16 to 19 July 2006 for verification of the models. We compared the observed hydrographs with the calculated hydrographs for water levels in the Shibayama and Kiba lagoons. Both of the calculated results were consistent with the hydrographic observations (Figure 3).

DEVELOPMENT OF A DIURNAL RAINFALL PATTERN GENERATOR

In our previous research, we developed a diurnal rainfall pattern generator that could reproduce the observed statistical characteristics of heavy rainfall in the study area (Minakawa *et al*., 2014a).



(a) Shibayama lagoon (b) Kiba lagoon

Figure 3. Comparison of observed and calculated water levels

The data are obtained as hourly data, and the model allows researchers to generate many heavy rainfall events with different temporal structures. The generator is based on the Markov-chain Monte Carlo method. The duration of the period of heavy rainfall can range from 1–3 days; in the present study, the duration was fixed at 3 days. Before applying the generator, rainfall events in which the 3-day rainfall exceeded a certain threshold (here, we used 100 mm/3 days) should be extracted from the daily and hourly rainfall data.

The generator software can perform any or all of four calculations: In calculation 1, the software describes the monthly event frequency using a Poisson distribution. In calculation 2, the software generates the total rainfall for each daily event using a gamma distribution based on historical rainfall data for the study area. In calculation 3, the software disaggregates the daily total rainfall into hourly data using a beta distribution. In calculation 4, the software rearranges the disaggregated data series by correcting for autocorrelation (described later in this paper). These four calculations are independent, so we can perform each calculation separately. Furthermore, because the calculations are independent, it is not necessary to base the input data for one calculation on the output data from another calculation. In this study, we only used calculations 3 and 4 (disaggregation and rearrangement) to generate the input rainfall data, as described in the following sections. The characteristics of the observed rainfall that we aimed to reproduce were the temporal distribution of rainfall intensity (at an hourly resolution), autocorrelation in the hyetograph, and variability of the temporal pattern.

<u>Disaggregation of Daily Rainfall into Hourly Data</u>

In this calculation, we disaggregated the daily rainfall into hourly data by considering the intensity distribution. We chose a duration of 3 days for rainfall events, so the total rainfall was disaggregated into 72 data points. We assumed that each hourly rainfall can be determined to multiplying the total rainfall amount by a distribution ratio that represents the proportion of the total rain that falls during each time step. Thus, the hourly rainfall was calculated as follows:

$$r_t = TR\ d_t \tag{5}$$

me step t (t = 1, 2, 3, …, T hours), and T is defined as 72 hours in this study. TR is the total rainfall (mm/3 days), and the value is fixed at a constant value for each event. The distribution ratio (d_t) is defined randomly for each time step, with the value ranging from 0 to 1 and $\Sigma\ d_t = 1$. We used the beta distribution to generate d_t:

$$f(w) = \frac{\Gamma(a'+b')}{\Gamma(a')\Gamma(b')} w^{a'-1}(1-w)^{b'-1} \tag{6}$$

where w is a uniformly distributed random number, and a' and b' are shape parameters of the beta distribution. The parameters are determined by trial and error until the disaggregation results resemble the observed data. From a previous study, it is known that heavy rainfall events, including extreme events, include a number of periods with small rainfall, including values less than 5.0 mm and some values of 0.0 mm (Minakawa and Masumoto, 2010). Weak rainfall accounts for most of the hourly data in such events. (In the study area, about 90% of the total; H. Minakawa, unpublished data.) In contrast, the probability of a heavy rainfall, such as a value more than 30.0 mm, is low (e.g. < 3%). The frequency distribution for hourly rainfall intensity can be expressed well by an exponential distribution (Masumoto, 1993). Therefore, these parameters should be chosen to transform the shape of the beta distribution to resemble that of an exponential distribution (i.e., $0 < a' < 1$, $b' \geq 1$).

We followed a three-step procedure to generate the distribution ratio in each time step: In the first step, we assumed that the ratio of the total rainfall (i.e. *TR* in equation (5)) equaled 1, and calculated d_1 (the value during time step 1) by multiplying 1 by β_1. Here, β_1 is a random number from 0 to 1 generated by using the beta distribution function. In the second step, we calculated the value 1 minus d_1, and used this as the ratio of the total amount in time step 2. The value of d_2 (the value during time step 2) is determined by multiplying the ratio of total amount in time step 2 by β_2, which is also generated from the beta distribution. In the third step, we calculate the value 1 minus the summation of d_1 and d_2 as the ratio of the total amount in time step 3. We repeat these three steps until the last time step, when $\Sigma\, d_t = 1$. The value of d_t is expressed as follows:

$$d_t = \left(1 - \sum_{k=1}^{t-1} d_k\right) \times \beta_t \tag{7}$$

<u>Rearrangement of the Hourly Rainfall Data Using an Autocorrelation Correction</u>

The calculations described in the previous section provide a data series that represents the intensity distribution for the hourly rainfall, but because of the nature of the calculations, the data are arranged randomly in this time series. In reality, intervals with similar hourly rainfall are often clustered, and sequential data for the observed hourly rainfall are often autocorrelated. The purpose of the present calculation is to rearrange the random distribution so that it more closely resembles a real distribution, which includes autocorrelation. To perform the rearrangement, we generated new quasi-rainfall patterns to use as a reference during the rearrangement. The quasi-rainfall pattern is generated sequentially by accounting for the correlation of the value in a given time step with the value from the previous time step.

<u>Generation of the quasi-rainfall data.</u> We assumed that the quasi-rainfall value, followed an exponential distribution, because we already knew that shapes of the frequency distribution for hourly rainfall intensity can be expressed by the distribution. The cumulative distribution function for the distribution is expressed as follows:

$$F(x_i) = 1 - \exp(-\lambda x_i) \tag{8}$$

where x_i is the value of the quasi-rainfall data at time step i ($i = 1, 2, 3, \ldots, T$), and λ is a parameter for the function that is calculated as follows:

$$\lambda = \frac{1}{\bar{x}} \tag{9}$$

where $\bar{x}$ is the statistical expectation of the data, and is calculated as the mean of the distributed rainfall data used for the rearrangement procedure. When i is 1, the value of x_1 is randomly extracted from the disaggregated data. The value of $f(x_1)$ at this time, given as u_1, ranges from 0 to 1. For the second time step, the correlation between x_1 and x_2 should be considered when x_2 is generated. If we generate u_2 (ranging from 0 to 1), which is correlated with u_1, the value of x_2 can be calculated by using an inverse function of eq. (8):

$$x_2 = -\ln (1 - u_2)/\lambda \tag{10}$$

To account for the correlation between u_1 and u_2, we assumed that u_2 depended on a triangular distribution function, with u_1 as the mode of the function. Under this assumption, the probability density function for u_2 can be expressed as follows:

$$f(u_2) = \begin{cases} C + \dfrac{u_2(M - C)}{u_1} & 0 < u_2 \leq u_1 \\ M - \dfrac{u_2 - u_1}{1 - u_1}(M - C) & u_1 < u_2 < 1 \end{cases} \tag{11}$$

where C and M are parameters that determine the shape of the function. We defined the relationship between the parameters as follows:

$$\left.\begin{aligned} M &= 2 - C \\ C &\leq 1 \end{aligned}\right\} \tag{12}$$

Figure 4 shows the probability density function for u_2 as a function of C and M, and the strength of the correlation between u_1 and u_2 can be adjusted by modifying the value of C. We can set C to any value, including negative values. If C equals 1, then M is also 1, and u_1 and u_2 are uncorrelated. Throughout the process to correct for autocorrelation, we can generate the amount of x_2 as a function of x_1. In the third time step ($i = 3$), the value of x_3 would be calculated similarly based on the value of x_2, and the procedure is repeated until the last time step (T). As a result of this procedure, the series of generated data shows autocorrelation between consecutive rainfall events. Because the data series are newly generated in each treatment, the pattern will differ between simulations

<u>Data rearrangement method.</u> In rearranging the data, two data series must be accounted for: the disaggregated rainfall data series, which has the characteristic rainfall intensities in the observed data, and the quasi-rainfall data series, which has the characteristic autocorrelation of real rainfall events. The next step involves adding the characteristic autocorrelation to the disaggregated data by changing the order of the disaggregated data.

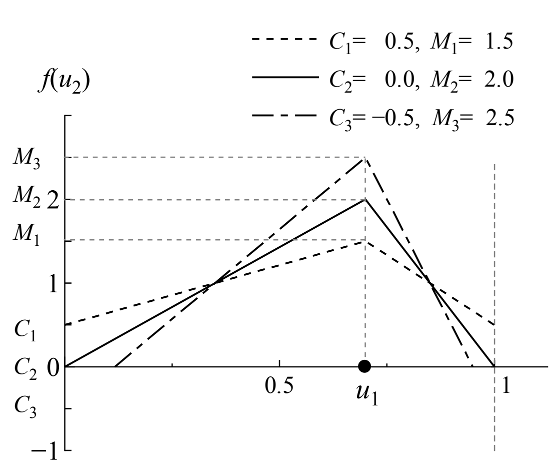


Figure 4. Changes of the Probability-Density Function for u_2 as a Function of the Values of Parameters C and M for an Example with $u_1 = 0.7$

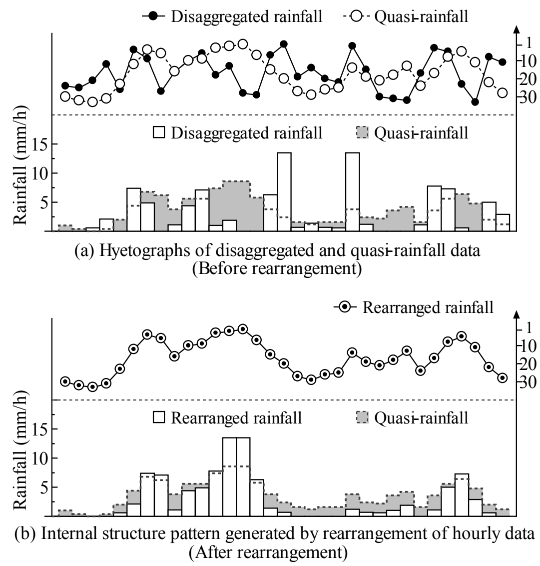


Figure 5. Rearrangement of the Generated Data by Using the Rank Order of the Rainfall Amounts

Figure 5 illustrates the rearrangement based on the autocorrelation correction in this method using the following procedure:

In the first step, all data in the quasi- and disaggregated rainfall series are ranked in order of intensity in each series (**Figure 5(a)**). At the same time, information about the initial positions of the quasi-data are stored along with the rank data. In the second step, the two ranked rainfall series are sorted into order based on their ranks. In the third step, the initial position of each value in the quasi-data is passed to the value with the same rank in the disaggregated data, and the disaggregated data are rearranged to use the position number from the quasi-rainfall series (i.e., the reference series). As a result, the rank order in the rearranged data becomes the same as in the reference series (**Figure 5(b)**), and the temporal pattern in the rearranged data more closely resembles a real pattern.

Verification of the Generator Output

We applied the generator to long-term rainfall data observed at the Kanazawa meteorological station, which is located about 50 km from the study area. The data span was 69 years (from 1940 through 2008), and daily and hourly rainfall data were collected. From the collected data, we extracted 3-day rainfall events with rainfall greater than 100 mm/3 days (Minakawa and Masumoto, 2010). We used this data (a total of 197 events) to verify the generator output. Comparison of intensity of hourly data was already finished (Minakawa *et al*., 2014), here the comparison of the variety of distribution pattern and autocorrelation coefficient of temporal structure were indicated. To describe the temporal structure of rainfall events in the observed and generated data, we graphed the temporal structure of each dataset using non-dimensional cumulative rainfall values, which were calculated by dividing the total rainfall by the cumulative value at each time step. **Figure**

6 shows the examples of the temporal patterns in the generated data. The results show a

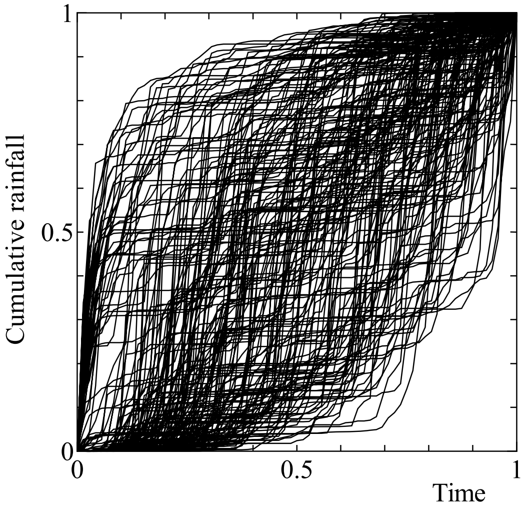


Figure 6. Temporal Distribution of the Generated Rainfall

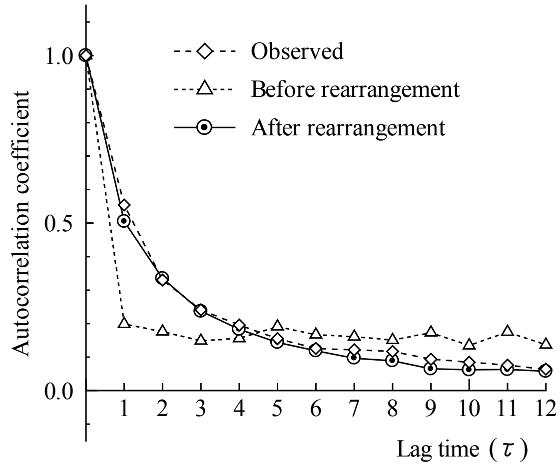


Figure 7. Correlograms for the of Rainfall Pattern

wide variation in the patterns. We estimated the autocorrelation coefficient in the observed data to be 0.55 in the case with a 1-hour lag time (τ), but the autocorrelation coefficient for the generated data was very close to the observed value (**Figure 7**). This demonstrates that the generated data had characteristics similar to the observed data, and could be used as the input data in our flood analysis.

PREPARATION OF THE FLOOD ANALYSIS

Generation of Heavy Rainfall Data

We created the input rainfall data using the generator, with a rainfall duration fixed at 3 days and the total rainfall fixed at an arbitrary size by using a probability distribution based on historical rainfall data for the study area. **Table 1** shows the probability of extreme rainfall events based on the statistically expected return interval. Here, we derived the 3-day rainfall for 10 return periods, ranging from 2 to 200 years. We estimated the future rainfall probabilities by using data from MIROC3_2_HIRES (Meehl *et al.*, 2007; Okada *et al.*, 2009), which is a general circulation model developed by the Centre for Climate System Research at the University of Tokyo, in cooperation with several institutes in Japan (Minakawa *et al.*, 2013). This model provides an example of predicted changes in the intensity of future heavy rainfall, but the return periods for extreme events are predicted to become shorter than in our simulation. The model suggests that the flood risk in low-lying areas will increase as a result of the predicted climate change. Each rainfall amount in **Table 1** was input as the total rainfall for the generator. The rainfall disaggregation into an hourly series was repeated 300 times for each rainfall, so that a given total rainfall had a range of different temporal patterns

(**Figure 8**). The generated data were all used as inputs for the flood analysis model, thereby providing 300 flood patterns for each rainfall amount.

Table 1. Amounts of Rainfall for 10 Return Periods

Return Period (y)	Rainfall Amount (mm/3 days)
2	141.0
3	163.6
5	187.8
8	210.4
10	220.4
15	238.2
30	268.1
50	290.0
100	321.9
200	350.9

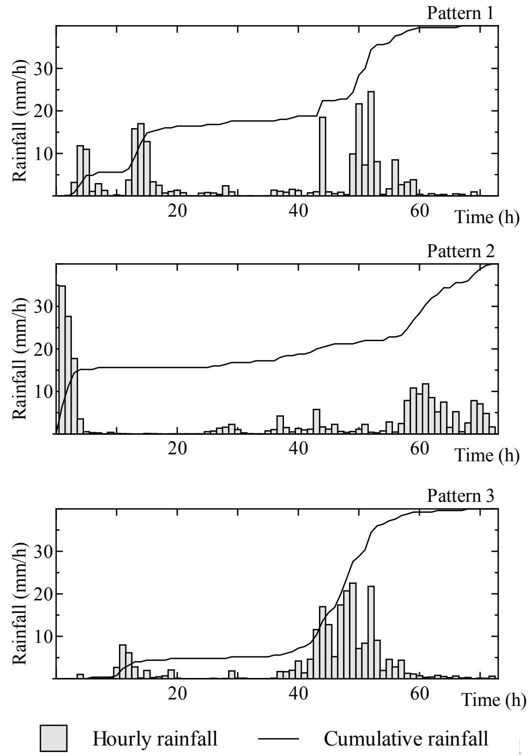


Figure 8. Examples of Three Input Rainfall Patterns
(Total: 220.4 mm/3 days)

Settings Used in the Flood Analysis Model

It is necessary to define upper and lower boundary conditions for the flood analysis model. We used the discharge from upland regions calculated using the kinematic-wave method as the upper boundary condition, and used the sea level as the lower one. The sea level is also predicted to rise as a result of climate change, and this could influence to the results of our water level calculations. However, since our goal in the present study was to evaluate the relationship between rainfall and flood risk, we did not attempt to simulate the effects of sea level changes near the study area. As the initial condition for all channel and paddy tanks, we used the same water level in each calculation. We set the calculation duration to 6 days (= 144 hours), and repeated the calculations 300 times for each rainfall amount. The results are presented at hourly intervals.

RESULTS AND DISCUSSION

Flooding Risk in Channels

In low-lying areas, information on the water level in rivers and other channels is important, and is often used as a criterion for warning local residents and farmers. In this study, we defined the risk of flooding by analyzing the calculated water level in the channels in our study area. The Shibayama Lagoon (tank no. 4 in **Figure 2a**) and a water level station immediately downstream of the Kiba Lagoon (tank no. 7 in **Figure 2b**, at the Miyuki Bridge point) were used in our risk assessment. The lagoons are important in

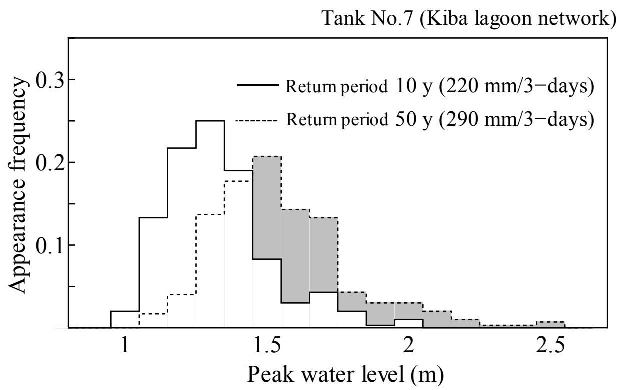


Figure 9. Frequency Distribution for the Peak Water Level

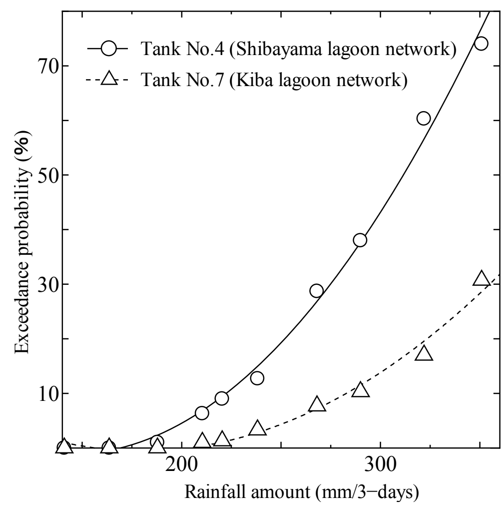


Figure 10. Relationship between Flood Occurrence Risk and Rainfall (Miyuki Bridge Point in the Kiba Lagoon Network)

terms of flood prevention in this basin, because outflow from upland areas and most discharge from the paddy fields are initially concentrated in the lagoons. In addition, the allowable flood level was established as 1.50 m in the Shibayama Lagoon, and as 1.80 m at tank no. 7 (Miyuki Bridge point). We used the results of all 300 patterns for each rainfall in the analysis.

First, we investigated the frequency distribution for peak water levels. **Figure 9** shows the result at the water level station in the Kiba Lagoon network (tank no. 7 in **Figure 2b**). The results show that the estimated peak water level is widely distributed, and depends on the temporal pattern of the rainfall, even when the total rainfall does not change. Based on these results, the frequency of exceeding the allowable flood level was estimated as the flood risk at each assessment point. We assumed that the risk could be calculated by dividing the number of simulations with a value greater than the allowable flood level by the total number of simulations (here, 300). This let us construct a curve for the relationship between total rainfall and the flood risk (**Figure 10)**. These results included the influence of both the amount and the temporal pattern of the rainfall. In future research, information on the damage to agriculture and other values in the basin can be added to these results to prioritize the planning of countermeasures against the impacts of climate change, such as reconsidering the drainage and pumping systems.

Flood Damage Risks in the Paddy Fields

The flood model simultaneously calculated changes in water depth in all paddy tanks. A main consequence of the flooding of paddy fields is damage that leads to a decrease in rice yields, leading to economic losses for the farmers. To account for these consequences, we assessed the risk of flooding by using both the peak water depth (**Figure 11**) and the duration of the flooding (**Figure 12**). Water level in the paddies changes in response to changes in the water level in channels connected to the paddies. Our simulations suggest that the time shift in the hydrographs depended on the rainfall

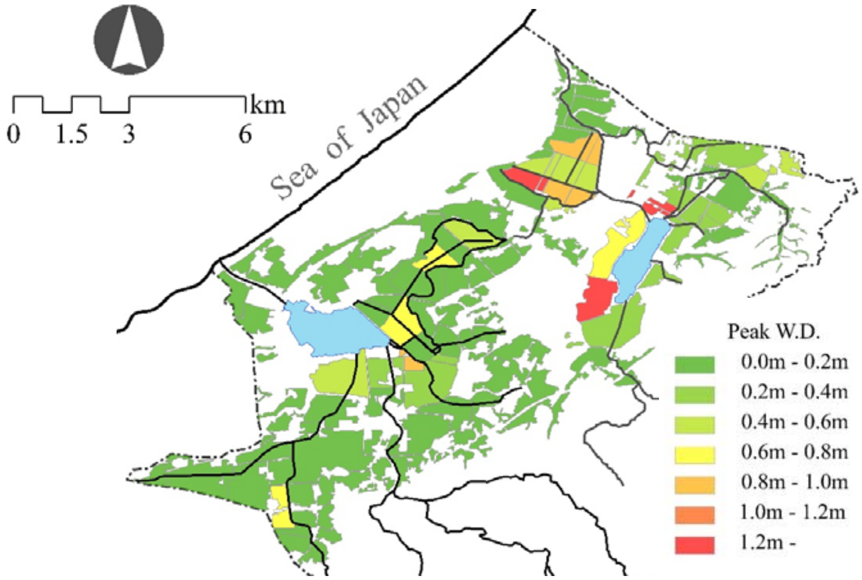


Figure 11. Distribution of the Peak Water Level in the Paddy Fields
(Example Based on Simulation Results with rainfall of 220.4 mm/3 days)

patterns and therefore resembled the water level trends in the channels. **Figure 11** provides an example of the distribution of peak water depths for a single rainfall pattern with a 10-year return period. The paddies that are vulnerable to heavy rainfall are easily visible. We defined a criterion for flooding as a water depth of more than 0.3 m based on the acceptable depth defined in drainage planning in Japan. We calculated the number of hours in which the water level exceeded this depth, and used that value to represent the flooding duration. **Figure 12** summarizes the range between minimum and maximum flooding duration as a function of rainfall based on the results of 300 simulations. These outputs could be utilized to predict the flooding damage in paddy fields, including damage to rice plants and other crops, after the flooding caused by heavy rainfall.

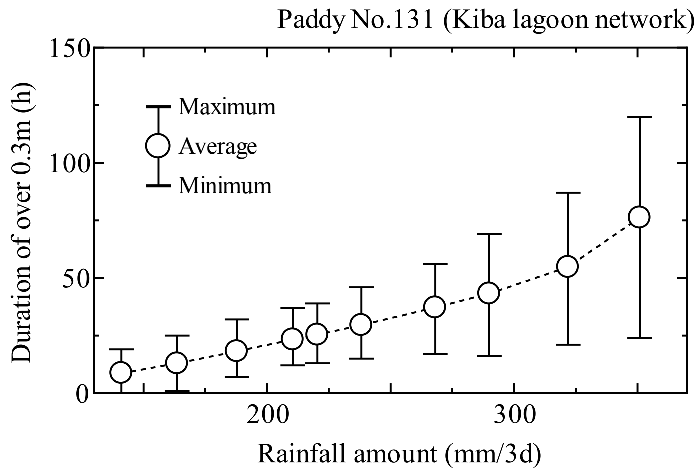


Figure 12. Average and Range of the Maximum Duration of Flooding to a Depth Greater Than 0.3 m (Example for Paddy Tank No. 131 in the Kiba Lagoon Network)

However, the degree of flooding damage to rice plants depends on various aspects of the flooding conditions, including the timing of the flooding (i.e., its relationship to rice phenology) and the duration of the flooding, making it difficult to accurately estimate the damage. We are currently attempting to formulate a damage scale based on rice yields that accounts for the relationship between flooding conditions and rice yield (Minakawa *et al*., 2014b). The effects of changes in water depth in paddy fields on rice yield will need to be studied in more detail, and the resulting models should be linked with the results of the present study to predict flooding damage to rice.

CONCLUSIONS

In the present study, we built on our previous research to develop a method for predicting the risk of flooding in low-lying areas, with the goal of supporting planning to mitigate the effects of climate change on the amount and temporal pattern of rainfall. The flood analysis model combines a kinematic-wave runoff model with a drainage analysis model. In addition, we used a rainfall pattern generator to more accurately simulate the temporal pattern of rainfall during heavy rainfall events. By calculating 300 temporal patterns for each rainfall amount and 10 return intervals, we stochastically assessed the flood risks for Japan's Kaga basin. Our results clearly showed that flooding risk depended both on the amount and the temporal pattern of the rainfall, and that our model provides a useful tool for predicting and mitigating the effects of future flooding that will occur as a result of climate change. Because climate change will have other effects on the Kaga three-lagoon basin's water resources (e.g., an increased frequency or duration of drought), it will be necessary to perform a more holistic evaluation of the impacts of climate change on agricultural water use. Extreme events such as flooding and drought strongly affect agricultural water use in monsoon Asia, as has been shown (for example) in Thailand (Vongphet *et al.*, 2014). Coupling of an analytical model for agricultural water use with a flooding model is already being done to develop a model that can calculate the effects of flooding and drought simultaneously (Vongphet *et al*., 2015). As this research advances, it will become easier to plan for sustainable water management in basins such as the Kaga three-lagoon basin.

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ADDRESSING CLIMATE CHANGE IMPACTS TO WATER RESOURCES IN RECLAMATION

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ABSTRACT

In 2009 Congress passed the SECURE Water Act authorizing Reclamation to assess the impacts of climate change on water resources and to analyze the extent to which those changes affect Reclamation's ability to meet its water delivery, hydropower, flood control, reservoir operations, and ecological resource obligations. Since 2009, Reclamation has collaborated with Federal and non-Federal partners to complete over 20 basin studies and multiple large scale impacts assessments analyzing these effects and developing mitigation strategies to resolve future water supply and demand imbalances for western river basins. This presentation will provide a brief overview of Reclamation's approaches to addressing climate change impacts on water supply (surface water, groundwater, and snowpack) and demand (irrigation, municipal) using ongoing or recently completed studies. For example, in the Hood River Basin Study, the impacts of climate change on Mount Hood glaciers, changes in stream flow, groundwater recharge, and conservation actions were evaluated. The Columbia River Basin Impacts Assessment will generate future climate change flows for use by others, detailed analyses on reservoir operations, and proof of concept studies on restoration and design projects. These studies will be presented along with an overview of funding opportunities through Reclamation's WaterSMART program.

INTRODUCTION

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public. This mission is at risk given the changes in weather, streamflow and increasing air temperature since Reclamation's formation in the early 1900s. Of particular importance is Reclamation's continued ability to deliver water and power to meet agricultural, tribal, municipal, and industrial water user needs as well as providing water for environmental flows (Reclamation 2014).

The SECURE (**S**cience and **E**ngineering to **C**omprehensively **U**nderstand and **R**esponsibly **E**nhance) Water Act (SECURE) was enacted by Congress in 2009 authorizing Reclamation to assess the impacts of climate change on water resources and to analyze the extent to which those changes affect Reclamation's ability to meet its water delivery, hydropower, flood control, reservoir operations, and ecological resource obligations. In 2010, the WaterSMART (**S**ustain and **M**anage **A**merica's **R**esources for **T**omorrow) Program was established to implement SECURE. SECURE authorizes Reclamation to assess the risks to water supplies posed by climate change, including changes in snowpack, in timing and quantity of runoff, groundwater recharge and discharge, as well as changes in demands and consumptive use within major river basins

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in the Western United States. SECURE further authorizes Reclamation to evaluate the impacts of climate change on specific components including water deliveries, hydropower, recreation at Reclamation facilities, fish and wildlife habitat, Endangered Species Act (ESA) species, water quality, flood control, and flow and water dependent ecologic resiliency.

STUDIES

This section describes two major studies conducted in the Pacific Northwest funded through Reclamation's WaterSMART Program.

Columbia River Basin Impacts Assessment

The Columbia River Basin Impacts Assessment (CRBIA) was initiated in Fiscal Year (FY) 2013. Assessments are 100 percent funded by Reclamation. Because the results (e.g., future climate change flow at specific locations) are available to practitioners in the Columbia River Basin for use in follow-on studies, input from other Federal, state, local agencies, Tribes, and other interested parties in the study area is critical. Quarterly email-updates, a mailing list, webpage and webinars are examples of ways Reclamation provided to interested parties to give feedback on the CRBIA or the process.

A primary focus of the CRBIA is to generate future climate change flow at more than 150 locations across the Columbia River Basin (Basin) and evaluated the potential impact of those flows at specific sub-basins within the Basin (**Figure 1**). With these flows, Reclamation will conduct more detailed analyses in the upper Snake River Basin (from the headwaters to Brownlee Reservoir including major tributaries) using the MODSIM-DSS (Decision Support System) reservoir model to evaluate how changes in water supply and demand will impact reservoir operations and environmental requirements. In addition, specific applications of the future climate change flow will be also used in hydraulic models that have been constructed for restoration efforts in the Grande Ronde basin (Oregon) and the Middle Fork John Day River (Oregon) basin.

These future climate change flows will be used to quantitatively evaluate the impacts associated with climate change as they relate to the mission of Reclamation. This will include risks to water supplies and any increase in the demand for water as a result of increasing temperatures and the reservoir evaporation rates for the Basin. The impacts of these changes will be analyzed on water delivery, ecological resources, flood control, and recreation at Reclamation facilities. To identify the risks and impacts to these components, the Assessment will use the best available science and climate information within a planning context at the reconnaissance level.

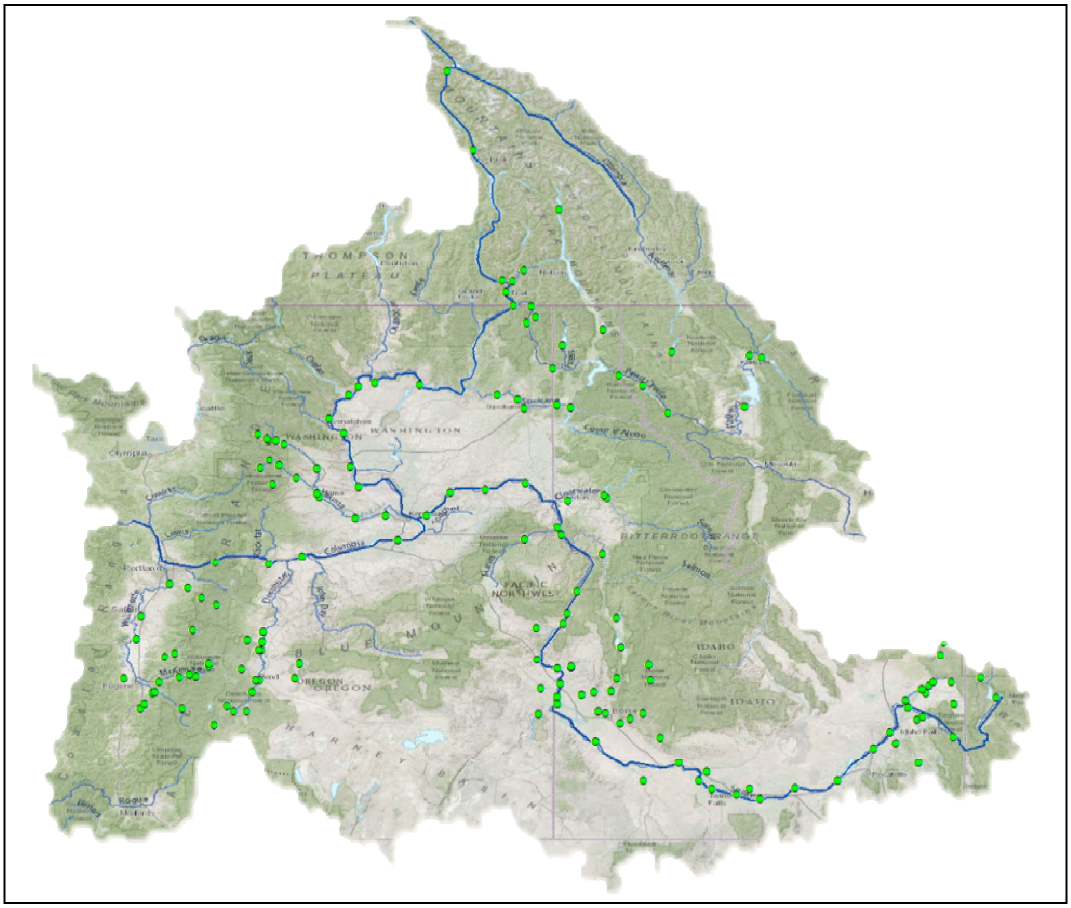

Figure 1. Columbia River Basin and approximate locations at which future climate change flow will be generated.

Hood River Basin Study

The Hood River Basin Study (Basin Study) was selected by Reclamation in fiscal year 2011 and completed in collaboration with Hood River County and the Hood River County Water Planning Group (HRCWPG). The HRCWPG was formed in 2008 to assess future water needs and includes Hood River County, Columbia Gorge Fruit Growers Association, Hood River County Soil & Water Conservation District, multiple water districts, Middle Fork Irrigation District (MFID), East Fork Irrigation District (EFID), Farmers Irrigation District (FID), Mount Hood Irrigation District (MHID), Dee Irrigation District (DID), Oregon Water Resources Department, Confederated Tribes of Warm Springs Oregon, Natural Resources Conservation Service, and various interested citizens of Hood River County. The funding for the Basin Study was through Reclamation's Basin Study Program under the WaterSMART Program and Hood River County, which was the non-Federal cost-share partner.

The Hood River basin is a 482-square-mile region located in northern Oregon extending from the summit of Mount Hood to the south, the ridgeline of the Cascade Range to the west, and the Columbia River to the north (**Figure 2**). The West Fork Hood River, the

Middle Fork Hood River, and the East Fork Hood River are the three primary forks to the mainstem Hood River. The Middle Fork and East Fork are fed in part by Mount Hood glaciers and combine to form the East Fork Hood River drainage. The mainstem Hood River, which joins the Columbia River near the City of Hood River, is located downstream of the confluences of the three forks.

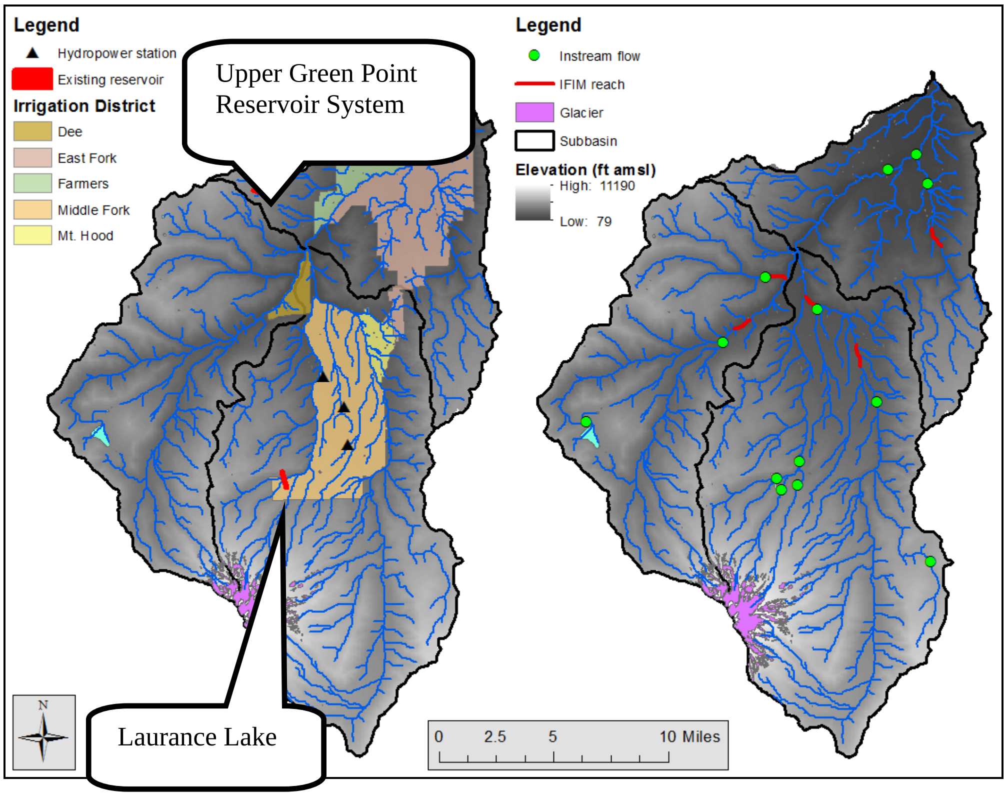

Figure 2. Hood River basin irrigation districts, reservoir system, instream flow study locations and stream network.

The economy of Hood River County is primarily dependent on irrigated agriculture. In 2010, raw agricultural commodity sales in Hood River County were $87,598,000 (Oregon State University Extension 2010). There are two major reservoir systems in the basin that deliver water in part for agriculture use that include Laurance Lake, located on a tributary to the Middle Fork Hood River and Upper and Lower Green Point reservoirs, located on Ditch Creek that drains into the mainstem Hood River. In addition to supporting agriculture, these reservoir systems also supply water for meeting instream flow requirements (discussed later), recreation, and several hydropower facilities. MFID operates Laurance Lake and three powerplants, and FID operates the Green Point Reservoir system and two powerplants near the mouth of the Hood River. None of these facilities are Reclamation owned or operated.

The impacts of climate change on streamflow, the Mount Hood glaciers, and snowpack were evaluated as part of this Basin Study. Three climate change scenarios were generated representing dry, median, and wet ranges of climate change through 2060.

These scenarios captured the full range of potential future climate in the basin. Future precipitation varied between a 33 percent decrease in the summer in the dry climate change scenario to a 12 percent increase in the wetter climate change scenario in the fall. Future average temperatures increased between 0.7ºC in the spring in the wet and 2.4ºC in the summer in the dry future condition. These results indicate that the air temperature will continue to increase in the future affecting water supply (surface water, glacier melt, snow melt) volume and timing, and water use (e.g., irrigation, hydroelectric power).

A water use assessment (Christensen and Salminen 2013) was completed detailing the existing water use in the Hood River County. A water conservation assessment (WPN 2013) was then completed identifying both current actions taken by water users in the Hood River basin and other actions planned for in the future. The results of these assessments were considered in the MODSIM-DSS reservoir modeling to help understand how a changing water supply would potentially impact water users in the Hood River basin.

General Results

- Climate change will affect streamflow peak flow timing and volume. Based on historical and future streamflow at 42 locations, all three climate change scenarios showed shifts of peak flow timing to earlier in the year and higher peak flow volume than historical streamflow.

- Since the 1920s, the snowpack extent as of April 1 of every year has trended downward at a rate of approximately 5 percent every 30 years and that pattern is expected to continue through 2060. This decrease in snowpack results in higher streamflow in the winter and lower streamflow runoff during the spring and summer months.

- Warming temperatures have also reduced the extent of the Mount Hood glaciers since the 1920s. Nolin (2007) reported that glacial melt contributed up to 74 percent of the streamflow in some tributaries to these forks during August and slightly less in September.

Alternatives. Six alternatives were evaluated that included conservation, two groundwater, and three new or enhanced storage. If no action is taken, potable and irrigation demands will continue to increase to further the water imbalances in the future, particularly during the summer months. The expected increase of groundwater pumping to meet future agricultural needs will add to those imbalances as groundwater extracted for irrigation use would further deplete summer time flows. The conservation, groundwater recharge for either storage (or augmentation), and storage alternatives were evaluated against the existing imbalances as well as the future imbalances determined in the increased water demands and pumping scenarios. While conservation through improved water delivery efficiencies addressed many of the identified gaps, enhanced storage water and groundwater injection benefited the water users in the future too.

WaterSMART Program Funding Opportunities

Through the WaterSMART Program, a number of funding opportunities were established. This list is not intended to be all-encompassing. Some opportunities are available every year, while others are only available every other year. Current information can be found at http://www.usbr.gov/WaterSMART/.

Table 1. WaterSMART Grants (table compiled by Rochelle Ochoa, Intern, Reclamation 2015)

Name	Amount	Stipulations
Water and Energy Efficiency Grants	Up to $300,000 for smaller projects; up to $1,000,000 for larger projects	Focuses on projects that can be completed within 24 months that will help sustainable water supplies in the western United States. Cost share is 50 percent Federal and 50 percent non-Federal
System Optimization Reviews Grants	Not available in 2015; grants are up to $300,000 and studies to be conducted within 24 months; 50/50 cost share	Focuses on future water management improvements; must be a State, Indian Tribe, irrigation or water district or other organization with water or power delivery authority
Advanced Water Treatment Grants	Funded amount varies; 50/50 cost share	Aim to encourage pilot and demonstration projects that address technical, economic and environmental viability of treating and using brackish groundwater, seawater, impaired waters or otherwise create new water supplies within a specific locale.
Grants to Develop Climate Analysis Tools	Not available in 2015; when funded, project costs can vary	Financial assistance opportunities to universities, non-profits and other organizations with water or power delivery authority
Drought Response Program	$1.5 mill	http://www.usbr.gov/newsroom/presskit/factsheet/factsheetdetail.cfm?recordid=10 – funding available FY2015
Resilient Infrastructure Investments	$1.5 mill-Details after 30 day comment period closes	
Title XVI-Water Reclamation and Reuse	Funded amount up to $150,000 for studies completed in 18 months; up to $450,000 for studies completed within 36 months; 50/50 cost share	Entities seeking new sources of water using water recycling and reuse technology
Basin Studies	Funded amount varies; studies to be conducted within 36 months; 50/50 cost share	Competitive annual process

CONCLUSION

"Adequate water supplies are an essential element in human survival, ecosystem health, energy production and economic sustainability" (http://www.usbr.gov/WaterSMART/). Climate change poses a significant risk to this natural recourse that will continue to exacerbate the many and sometimes conflicting demands placed on it. Reclamation continues to actively pursue paths to better conserve existing water supplies and plan for future changes in both the timing and volume of runoff due to a warming climate. WaterSMART is a tool that allows Reclamation to work with States, Tribes, local governments, and non-governmental organizations to pursue a sustainable water supply. Reclamation will continue to seek partnerships to sustain use of all natural resources.

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FUTURE WATER AVAILABILITY FOR AGRICULTURE IN SAR (2050): CLIMATE CHANGE, POPULATION GROWTH, AND LAND USE PATTERNS

Jorge Escurra[1]

ABSTRACT

Although the South Asia Region (SAR) has faced a long period of robust economic growth, averaging 6% a year over the past 20 years. SAR is still considered the region with the home to many of the developing world's poor. It is known that about 1.5 billion people are affected by water stress and scarcity, due to increasing demand for water resources; as the climate changes, population growth, and cities expands; thus making the situation worse. The paper aims to assess the impacts of climate change, land use patterns, and population growth in the basins within SAR by analyzing their effects over the water availability (with focus on irrigation) for the period between 1950 and 2000. To reach this objective a conceptual water balance model called WASD-PUB, which includes contributions from snow-melting and storage capacity from reservoirs, for the South Asia region was developed using public domain georeferenced information. WASD-PUB calculates the amount of water supply and demand for a baseline (1950 – 2000) and its projection to 2050 considering: (i) the downscaled outputs from nineteen Global Circulation Models (GCMs) from the Coupled Model Intercomparison Project Phase 5 (CMIP5) RCP 4.5; (ii) the population growth projected to 2050; and (iii) land use patterns in the last years at country level. The paper identifies the "hot spot" basins in which irrigation investments (such as construction of reservoirs, lining of canals, improvement of on-farm irrigation efficiency, and providing technical capacity to farmers) oriented to improving water efficiency is a key action to confront water scarcity in 2050.

INTRODUCTION

Water is an essential part of life and roughly one in ten of the world's population—748 million people—do not have access to safe water (WHO/UNICEF, 2014). In South Asia Region (SAR), about 1.5 billion people are affected by water stress and scarcity, due to increasing demand for water resources. This situation may worsen as climate change, population growths, cities expand.

This research paper aims to assess the impacts of climate change, population growth, and variation in land use in the basins within SAR by analyzing the hydrological cycle of the region and prioritizing the twenty basins within SAR based on the relation between the historical and future supply and demand of water. The future scenario is analyzed based on the following: (i) the downscaled outputs from nineteen Global Circulation Models (GCMs) from the Coupled Model Intercomparison Project Phase 5 (CMIP5) to 2050; (ii) the population growth projected to 2050; and the projection of change of land use in 2050 based on the observed land use patterns during the last years. The paper takes the approach following the basin perspective (including basins which are shared by two or

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three countries), the basin perspective is the linchpin for understanding the amount of available water and water allocations to different users, especially when considering ways to improve water use is part of the objective (Molden et al, 2001).

The paper is divided into the following sections: (I) Overview of the Water Sector and Land Use Pattern in SAR; (II) Study Area; (III) Methodology; (IV) Results; (V) Conclusions. The first section, Overview of the Water Sector and Land Use Pattern in SAR, addresses the description of water management impacts from climate change; the current water resource management status quo; the importance of water security in the region; and an overview of the land use patterns during the last years. The second section, Study Area, limits the area of study and provides its physical description. The third section, Methodology, focuses on data inputs and approach to set the WASD-PUB spreadsheet model (including the equations and assumptions used in the construction of the model). The fourth section, Results, presents the outputs of WASD-PUB, the relation between the historical and future water supply and demand using two new sets of indicators (Modified Water Scarcity Index and Variability of Water Efficiency), then scenarios related to irrigation investments are analyzed and the hot stops basins are identified. The fourth section also involves the validation of the data using information from scientific papers, technical documents, and public domain web-based platforms used by multilateral organizations and researchers. Finally, the fifth section, describes the conclusions from the results of the paper.

OVERVIEW OF THE WATER SECTOR AND LAND USE PATTER IN SAR

SAR is still considered the region with the home to many of the developing world's poor. According to WHO/UNICEF Joint Monitoring Programme (JMP) for the water supply and sanitation (2013), SAR has 170 million of people without access to safe water and 1,005 million of people without access to improved sanitation facilities. SAR has the highest number of people in the world without access to improved sanitation. The statistics indicates that more strategies and investments need to be implemented in the region in order reach a point in which the number of the developing world's poor is reduced. An estimation of the cost of closing the infrastructure gap to invest on transport, electricity, water supply and sanitation, solid waste management, telecommunications, and irrigation is as much as US$ 2.5 trillion (Andres et al, 2013).

In addition SAR faces conflicts related to water scarcity which, some way, have contributed to slow down the region's development and negatively impacts in the life of the people, mainly those who are below the poverty line. In 2010, Pakistan filed a case in the International Court of Arbitration accusing India's Kishanganga hydropower project on the Neelum River in Kashmir of violating the Indus Water Treaty of 1960. The court issued an interim order allowing India to continue work at the site. However, the dispute continues, adding to tensions between the two countries. In addition, trying to obtain flow data information in India is very difficult or almost impossible because India's Farakka Barrage across the Ganges River has been a sore point in Indo-Bangladesh relations ever since its completion in 1975 (Langton and Prasai, 2012). The lack of flow data, measured in the field, makes impossible the calibration and validation process of hydrological and hydraulic models, causing the production of inaccurate results; thus, creating, a negative impact in the innovation of science in the water sector. In addition, for the first time in 2011 the United States raised water-related issues in its bilateral relationship in Afghanistan and Pakistan. The United States strategy and foreign assistance budgets included significant investments allocated toward activities that promote water security through high-visibility projects, such as expanding water storage capabilities and irrigation (Prepared for the Use of the Committee On Foreign Relations, United States Senate, 2011). This measurement came as part of the reconstruction process of the war in Afghanistan which started in 2001 by the intervention of the North Atlantic Treaty Organization (NATO) and allied forces.

Climate change effects have been impacting the region. Some proven examples of the effects among others are glacier melting, increment of temperature, and seasonal pattern of flows over the year that would become more erratic as rainfall is immediately converted to runoff instead of being stored as ice.. The total climate change cost in South Asia will increase over time and will be substantially high in the long term. Without global deviation from a fossil-fuel-intensive path, South Asia could lose an equivalent 1.8% of its annual gross domestic product (GDP) by 2050, which will progressively increase to 8.8% by 2100 (Asian Development Bank, 2014).

Although effects of climate change in Asia are affecting the water availability, it is not possible to generalize that these impacts will be negative or positive in all the basins. Due to difference in size of population, possible change of temperature and precipitation as result of climate change effect, soil characteristics, size of the irrigated or rainfed land, and others, the climate change impacts could bring a positive impact in some basins. For instance in the Yellow River, climate change may even yield a positive effect as the dependence on meltwater is low and a projected increase upstream of precipitation, when retained in reservoirs, would enhance water availability for irrigated areas (Immerzeel et al., 2010). Understanding the timeline of the glacier melting process is still an ongoing work. More recent work has shown that in some parts of SAR, glaciers have been increasing in mass over the last decade – the “Karakoram anomaly” (Hewitt, 2005; Gardelle et al., 2013). The historical land use patterns in each country in SAR has been driven by population growth, migration due to economic development (capital and labor), degradation of the environment, and wars/conflicts.

India

India has 62.4 million urban populations at the 1951 census, and this number has increased to 285.3 million in 2001. This means its urban population has increased to almost five times during the last fifty years. In recent years, approximately 6-7 million people have been added every year to the country’s total population. In addition, statistics have shown that southern and western states of India are generally more urban than those in the north and east. Also, it is known that area under forests, which includes all lands classified as forest under any legal enactment dealing with forests or administered as forest (state-owned or private), increased by 28.7 million ha from 1950-51 to 1999-2000 (by 22.5 %). However, some authors indicate that this is not because of a real increase of the forest, but this is due to increment of reports from areas under forest which were not considered before (Chadha et. el., 2004). Area under non-agricultural use, which includes all lands occupied by buildings, roads, railways or under water (e.g. rivers and canals and other put to uses other than agriculture), increased by 13 million ha from 1950-51 to 1999-2000. The increase in land under non-agricultural use may be attributed to rise in urban population as well as launching of development programs for boosting the economy of the country. The net area sown, which is the total area that is irrigated at least once per agricultural year, and does not include areas that were left fallow or entirely rainfed during the year of statistics, increased by of 22.48 million ha from 1950-51 to 1999-2000. In addition, area sown more than once, on which crops are cultivated more than once during the agricultural year, has moved up from 13.14 million hectares to 48.51 million hectares during the period of study (Mohanty, 2009).

Bangladesh

With the growing population, and their increasing needs in various sectors, land use patterns are undergoing a qualitative change in which the areas under the net sown land, and forest land is gradually shrinking. For instance, a land use pattern study developed in the Rajshahi District for the years 1977, 1990, and 2010 shown that the agricultural land, fallow land, river area, and water bodies have decreased, whereas the urban area have increased substantially. The agricultural land decreased by 14 % from 1977 (186056.7 ha) to 2010 (159913.48 ha), indicating a reducing rate of 0.46% per year. If this rate continues, no agriculture land would be available within the next 217 years. On the other hand, the urban area increased by 194 % from 1977 (16161.4 ha) to 2010 (47617.58) (Islam et al., 2011).

Afghanistan

The land use patterns is difficult to understand due to the years of violence which result on migration mainly to neighboring countries, deterioration of infrastructure (i.e dams, irrigation canals, and intakes), water rights infringement through the emergence of local (big and small) warlords and commanders, growing of opium (illegal crop) due to its high profit, among others. However, it is clear that forested area has reduced by 34 % from 1990 (1309000 ha) to 2005 (867000 ha) (FAO, 1997).

Nepal

Nepal is facing scarcity of land in terms of availability of cultivable land. For instance, per household land availability was 0.8 ha and 0.6 ha in 2001 and 2008, respectively (Central Bureau of Statistics, 2009. With the doubling of population in every 30 years, land availability per capita is declining more or less at the same rate as there is less scope to move to non-farm sector. The Land Reform Mapping Project (LRMP) survey reveals that as of 1985/86, 21 % of the land was cultivated, 7 % was uncultivated land inclusions, 12 % was pasture, 37 % was forest and 5 % was degraded forest, and 18 % was under other uses water, ice and lakes. From 1986 to 2000, there is significant change in land use pattern. The area under agricultural use has increased significantly by 20 %, and the forest area by 9 % (FAO, 2010). However, according to a land use pattern study developed for the city of Kathmandu, the urban area increased by 149 % from 1989 (17.92 Km2) to 2009 (44.66 Km2), the forested area reduced by 600 % from 1989 (5.69 Km2) to 2009 (0.81 Km2), and the cultivated land reduced by 142 % from 1989 (37.55 Km2) to 2009 (15.17 Km2) (Rimal, 2011).

Pakistan

According to a land use study pattern in the District of Lahore, the urban land use increased by 68 % from 1972 (58977 ha) to 2009 (99173 ha), the agriculture land reduced by 34 % from 1972 (95838 ha) to 2009 (63338 ha), and the forest land also reduced by 86 % from 1972 (5706 ha) to 2009 (856 ha) (Riaz, 2013). The District of Swat, which is part of the high altitude Hindu Kush Himalaya (HKH) region of Pakistan, faces problems of deforestation mainly due to expansion of the agriculture land. An analysis of land use and cover change over four decades was developed using aerial photographs and remote sensing data for the years 1968, 1990 and 2007. Annual deforestation rates observed were 1.86% (scrub forest zone), 1.28% (agro-forest zone) and 0.80% (pine forest zone). Authors concluded that despite frequent claims of forest increase in Swat, the valuable coniferous forest has significantly decreased, frequently leading to land degradation (Qasim et al., 2013).

Sri Lanka

Sri-Lanka faces an increment of the net cultivated land and a decrement of the forest area since 1970 to 2000. The net cultivated land increased by 17.5 % from 1970 (20,000 km2) to 2000 (23,500 km2). The forest area reduced by 35 % from 1970 (32,000 km2) to 2000 (23,500 km2) (Goldewijk et al., 2004). The growth of urbanization patterns in Sri Lanka is slow. It is evident that the rate of urbanization over the past 50 years has been very slow and the share of urban population remains below 25% of the Country's population. In addition, the amount of population who migrates from rural to urban areas is low. This may be due to several factors such as the smaller size of the country allowing people to reach towns and cities within a reasonable time, and then to move back to their place of residence, low transport costs, and reasonable infrastructure development. During the past four to five decades the government's priority has been investing in the rural agricultural sector and plantation sector. Major irrigation schemes and developments in district town centers with health, schooling, banking and other services may have held back migration to the cities (Empowerment, 2002).

STUDY AREA

The total area for SAR is close to 5.1 million km2. The research paper focuses on the basins that are located within the countries of the SAR. However, if the basins have boundaries in other countries outside of SAR, the area within those boundaries outside SAR were considered as well as part of the study area. The study area consists off twenty (20) major basins: (i) Amu Darya; (ii) Arabian Sea Coast; (iii) Caspian Sea - East Coast; (iv) Cauvery; (v) Farahrud; (vi) Ganges - Bramaputra -Meghna; (vii) Godavari; (viii)

Hamun-Mashkel; (ix) Helmand; (x) India North East Coast; (xi) Indus; (xii) Krishna; (xiii) Mahandi Brahamani; (xiv) Mahi Tapti Narmanda, and Purna River Basins; (xv) Parangi Aru / Yan Oya / Kala Oya / Mahaweli Ganga; (xvi) Pennar India East Coast; (xvii) Sabarmati; (xviii) Sahyadri Ghats Mtns. (West & Southern); (xix) Walawe Ganga / Kirinda / West Coast; and (xx) Yasai (Lehner et al., 2006). These basins cover an area of 5.5 million square kilometer (including areas of countries outside SAR). It is important to highlight that some of these basins are shared between two (Indus, Sabarmati, and Hamun-Mashkel) or three (Ganges - Bramaputra –Meghna) countries within SAR.

Figure 1 shows the different major basins for SAR and their elevations in meters above the sea level (m.a.s.l). As it is shown SAR has elevations that go from 8,848 m.a.s.l to values lower than zero m.a.sl (Jarvis et al., 2008). The drastically change of elevations in the region is one of the factors for high sediment loading, presence of micro-climate (includes drastically change of precipitation gradient in short distances), salinity intrusion from the sea (in zones with elevation lower than zero m.a.s.l), presence of glaciers, among others. The topographic regions in SAR are made up by the Himalaya, Karakorum, and Hindu Kush mountain ranges and their southern slopes, the Indo-Gangetic plain, and the Deccan plateau.

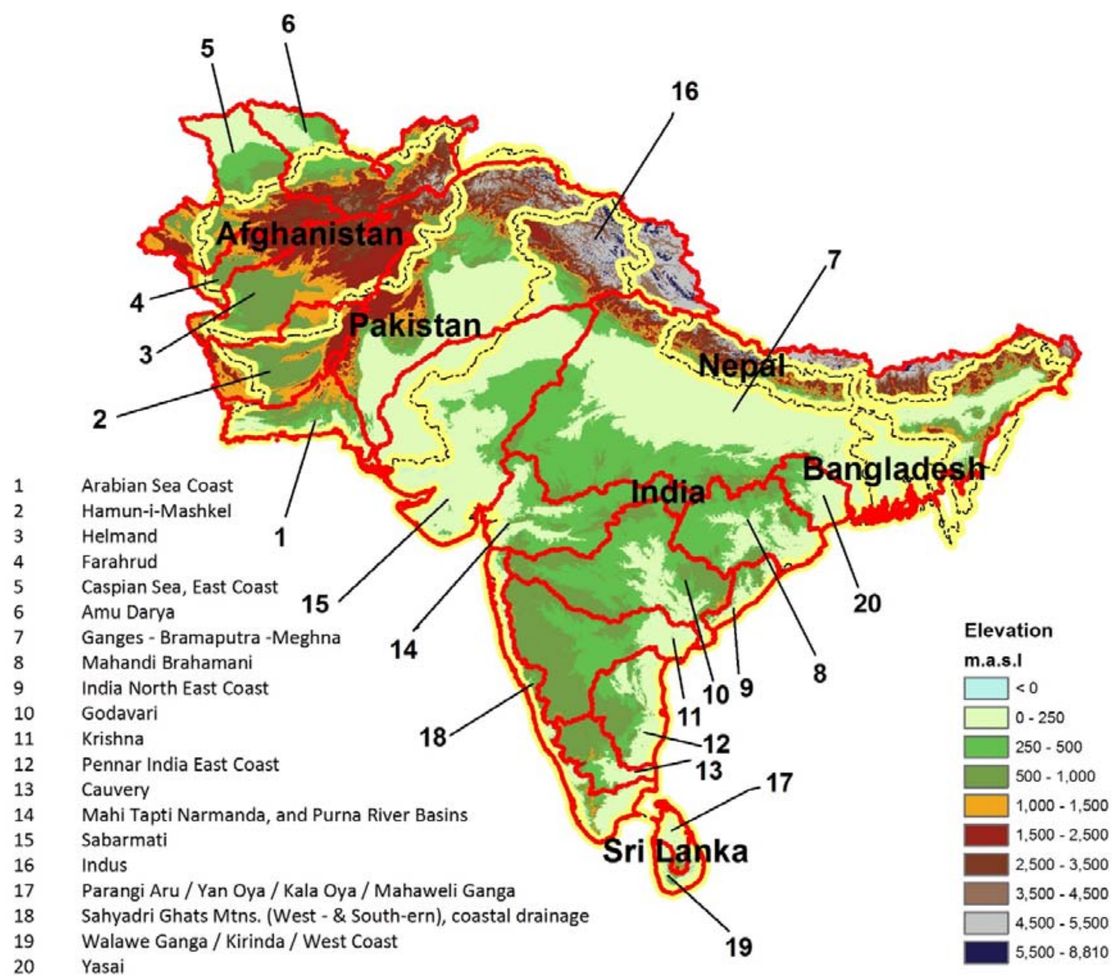

Figure. 1. Topographic Characteristics of SAR with Basin and Country's Boundaries

Figure 2 shows the land use map (2000) within the major basis in South Asia (Stibig et al., 2003), cropland is the major land use in the region with 3'019,000 km2, a little more than 50 % of the total area of SAR.

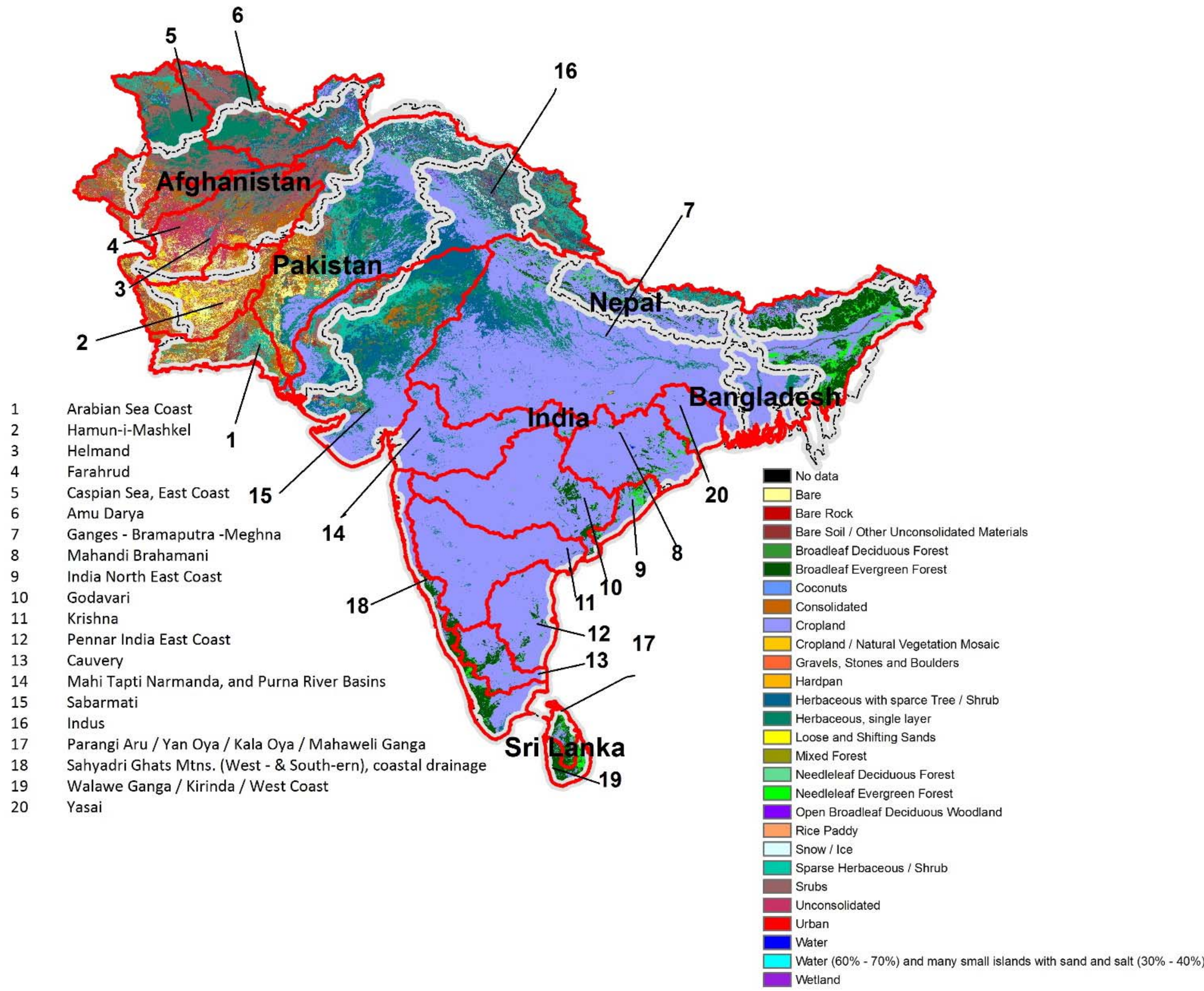

Figure 2. Land Use Map within the Basins of SAR.

Information regarding, irrigated land, glaciarized area, storage capacity, and population (year 200) was obtained from public domain web-based platforms and aggregated at the basin level. Table 1 shows a summary of the information at basin level.

Table 1. Summary of the Topographical, Agricultural, and Demographical Characteristics.

Basin	Area (km2)	Countries within SAR	Maximum/minimum elvation (m.a.s.l)	Irrigated area (km2)	Storage capacity (MCM)	Glaciarized area (km2)	Population year 2000 (N° Habitants)
Arabian Sea Coast	122,320	Pakistan	2906/-52	3,665	1,140		13’385,597
Hamun-i-Mashkel	166,072	Pakistan, Afghanistan	3916/481	2,808	0		2’462,825
Helmand	250,573	Afghanistan	4993/440	11,760	3,158		6’067,094
Farahrud	65,583	Afghanistan	4141/449	3,067	0		722,735
Caspian Sea, East Coast	243,930	Afghanistan	4450/114	9,617	5,454		3’724,436
Amu Darya	232,903	Afghanistan	6790/158	16,315	1,555	1,035	8’708,600
Ganges - Bramaputra -Meghna	1’712,905	India, Nepal, Bangladesh	8806/-37	35,0075	82,556	18,237	598’641,216
Mahandi Brahamani	173,528	India	1321/-28	17,576	15,793		44’759,864
India North East Coast	42,502	India	1631/-14	7,838	1,276		12’538,020
Godavari	313,892	India	1664/-25	38,841	27,057		63’982,612
Krishna	232,116	India	1903/-35	53,871	49,589		80’010,952
Pennar India East Coast	115,622	India	1632/-70	21,757	2,283		44’692,628
Cauvery	67,870	India	2623/-9	16,396	7,780		32’128,042
Mahi Tapti Narmanda, and Purna River Basins	184,076	India	1556/-32	28,435	29,909		51’323,592
Sabarmati	472,851	India Pakistan	1888/-56	127,681	1,081		90’688,432
Indus	867,157	India Pakistan	8569/-44	152,958	49,305	20,945	150’703,696
Parangi Aru / Yan Oya / Kala Oya / Mahaweli Ganga	24,818	Sri Lanka	2518/-12	3,308	3,678		5’117,558
Sahyadri Ghats Mtns. (West & Southern)	122,404	India	2674/-39	16,961	17,030		79’414,720
Walawe Ganga / Kirinda / West Coast	29,639	Sri Lanka	2318/-13	2,567	1,815		13’106,588
Yasai	62,077	India	1359/-8	11,606	82,556		36’119,632

METHODOLOGY

Input data

The objective of the paper was achieved using primarily data from public webpage domain. As it is known, most of this information covers the entire world and it was developed based on satellite images, interpolated, and aggregated data. In addition, this information data needs to be calibrated and validated with field observation. Therefore, in areas where field observations are a constraint (due to lack of resource for purchasing equipment, vandalisms, and inaccessibility due to topographical characteristics [especially in steep zones and mountainous areas], to frequent natural disasters, and to disputed or conflict zones), this information needs to be taken with caution to avoid inaccurate results which conveys wrong messages to decision makers and communities.

The input data was collected from different sources and at different resolutions. Table 2 shows the type of data, source, web-link where it was downloaded, as well as resolution, units, and the year that it was gathered.

Table 2. Information Regarding Input Data Used in for the Analysis.

Type of data	Source	Web-link	Units	Resolution	Year
Population	Socioeconomic Data and Application Center (SEDAC)	http://sedac.ciesin.columbia.edu/data/set/gpw-v3-population-density	Habitants	5 x 5 km	2000 and 2015
Elevation	The CGIAR Consortium for Spatial Information (CGIAR – CSI)	http://srtm.csi.cgiar.org/SELECTION/inputCoord.asp	m.a.s.l	90 x 90 m	2008
Annual temperature and precipitation	The Nature Conservancy and Univ. of Washington	www.climatewizard.org	ºC, mm	50 x 50 km	1951-2002
Average Annual Precipitation	King's College London, CIAT, and Universidad Nacional de Colombia	http://www1.policysupport.org/cgi-bin/ecoengine/start.cgi	mm	1 x 1 km	1950-2000
Average Annual Actual Evapotranspiration	King's College London, CIAT, and Universidad Nacional de Colombia	http://www1.policysupport.org/cgi-bin/ecoengine/start.cgi	mm	1 x 1 km	1950-2000
Average Annual Potential Evapotranspiration	King's College London, CIAT, and Universidad Nacional de Colombia	http://www1.policysupport.org/cgi-bin/ecoengine/start.cgi	mm	1 x 1 km	1950-2000
Average Annual Run off	King's College London, CIAT, and Universidad Nacional de Colombia	http://www1.policysupport.org/cgi-bin/ecoengine/start.cgi	mm	1 x 1 km	1950-2000
Annual Snow-melting	King's College London, CIAT, and Universidad Nacional de Colombia	http://www1.policysupport.org/cgi-bin/ecoengine/start.cgi	%	1 x 1 km	1950-2000
Location of Glaciers	National Snow and Ice Data Center	http://nsidc.org/data/g01130	Lat and long, area (acre), snow depth (ft)	None	2012
GCM outputs for temperature (RCP 4.5)	WorldClim - Global Climate Data	http://www.worldclim.org/tiles.php	ºC	1 x 1 km	2050
GCM outputs for precipitation (RCP 4.5)	WorldClim - Global Climate Data	http://www.worldclim.org/tiles.php	mm	1 x 1 km	2050
Delineation of basins	USGS- HydroSHEDS	http://hydrosheds.cr.usgs.gov	Latitude and longitude	None	2006
Dams	NASA's Earth Observing System Data and Information System (EOSDIS) — Hosted by CIESIN at Columbia University	http://sedac.ciesin.columbia.edu/data/set/grand-v1-dams-rev01	Latitude and longitude	None	2011
Reservoir	NASA's Earth Observing System Data and	http://sedac.ciesin.columbia.edu/data/	Latitude and	None	2011

	Information System (EOSDIS) — Hosted by CIESIN at Columbia University	set/grand-v1-reservoirs-rev01	longitude		
Irrigated area	Food and Agriculture Organization - Aquastat	http://www.fao.org/nr/water/aquastat/irrigationmap/index10.stm	ha	10 x 10 km	2005
Water/irrigation efficiency	Potsdam Institute Climate Impact Research	https://www.pik-potsdam.de/research/publications/pikreports/.files/pr104.pdf	%	10 x 10 km	2006
Land use cover	European Commission	http://bioval.jrc.ec.europa.eu/products/glc2000/products.php	Type of land use	1 * 1 km	2000

The input information was cleaned, corrected, and analyzed using the functions of the software ArcGIS 10.1 from Environmental Systems Research Institute, ESRI, (i.e Append, Extract from Mask, Polygon to Raster, Raster calculator, and others).

The FIESTA hydrological model (Mulligan and Burke 2005; Mulligan et al., 2010; Bruijnzeel, Mulligan and Scatena 2011) and previous policy support systems including DESURVEY PSS) were also used. When used inside the Andes mountain range the system is referred to as AguAAndes. When applied elsewhere in the world the PSS is referred to as WaterWorld.

The data related to the hydrology of SAR was calculated using the online policy support system (PSS) WaterWorld based on the FIESTA hydrological model (Mulligan and Burke, 2005). This tool is a sophisticated model of spatial water balance which has been developed for data poor and spatially complex and heterogeneous environments. The model includes modules for distribution of rainfall through interaction with wind, occult precipitation through fog inputs, solar radiation receipt, potential and actual evapotranspiration on the basis of climate and vegetation cover, water balance and its accumulation downstream as runoff. There is also a simple model for soil erosion. The model requires some 140 inputs maps (all of which are provided with the system, globally) and calculates annual hydrological variable including water balance, runoff and soil erosion for a baseline representing year 2000 land cover and mean 1950-2000 climate. Given the lack of global data on groundwater resources Waterworld does not simulate subsurface hydrological processes associated with flows in soil and groundwater (Mulligan and Burke, 2005). Waterworld was used as the main supplier of hydrological indicator such as precipitation, snow-melting, actual evapotranspiration, and potential evapotranspiration, run off at the end of the major basins. This information along with additional data gathered from other sources were used as input to develop a water balance model developed in an Excel spreadsheet called “WASD-PUB” that stands for Water Supply and Demand Calculations Based on Public Domain Information.

Calculation of the Average Annual Water Supply and Demand (1950 -2000)

The calculation of the average annual water supply and demand WASD-PUB responds to the spatial distribution of the continuity equation at basin scale. The temporal scale is based in the annual average values from 1950 to 2000. The WASD-PUB uses information from public domain webpage for the period of 1950 to 2000, especially the hydrological indicator data. However, a few data such as dam location and characteristics, irrigation area and efficiency, and elevation are from a few years after 2000. In the specific case of dams, only dams that were in functionality during the period were considered. Irrigation area and efficiency were from 2005 and 2006, respectively. Irrigation area was verified with the land use data from 2000 and no major change was observed. Because surface irrigation is still being the most use irrigation system in SAR by far, there is not much change of irrigation efficiency after six year at country level. In addition, WASD-PUB requires some information from users which will allow to refine the inputs considered in the calculations. WASD-PUB does not consider artificial trans-boundary among basins. The input information needed from users are: (i) daily water consumption per capita (l/day); (ii) the reservoir yield in percentage (%) of the total storage capacity if reservoir is considered as supplier of water in the basin; (iii) water demand for industrial use or others as percentage of total water demand; (iv) percentage of snowmelting reduction with the increment of 2 degrees Celsius; (v) percentage of increment of industrial water use by 2050; (vi) daily water consumption per capita (l/day) by 2050; and (vii) estimation of change of storage capacity by 2050.

The rationale of the main water balance equation is based on Equation 1. Water supply is calculated based on the amount of precipitation and snow-melting, information related to the storage capacity in each basin.

$$\text{Water supply}_{(k)} = \text{Precipitation}_{(k)} + \text{Snowmelting}_{(k)} + C_1 \times \text{Storage capacity}_{(k)} \quad (1)$$

Where Water supply is the annual average water supplied for each basin for the baseline (1950-2000), and C_1 is a coefficient that represents the reservoir yield in percentage (%) of the total storage capacity during a year.

Based on previous work developed in the Ganges and Indus basin, the operation management of the dams in the region indicates that the reservoir yield in percentage (%) of the total storage capacity in a year is between 60 - 75 %. For this case, C1 has a value of 70 %. However, this could be modified by the user, and get a new set of results.

Equation 2 shows how the water demand for each basin is calculated based on adding the agriculture, domestic, and other water use demands (including industrial).

$$\text{Water demand}_{(k)} = \text{Agriculture demand}_{(k)} + \text{Domestic demand}_{(k)} + \text{Industrial demand}_{(k)} \quad (2)$$

Where Water Demand is the annual average water needed for the baseline (1950-2000), k is the total number of basins (20), Agriculture demand is the annual average water amount needed for green areas, water bodies, Domestic demand is the annual average water needed for satisfy the human consumption based on the population in 2000, and Industrial demand is the annual average water needed to satisfy the industrial activities, depends on the industrial and economic development.

The calculation for each type of demand is as follows:

The agriculture demand is calculated based on the Actual evapotranspiration (ETA), the irrigated area, and the water efficiency at basin level. The water efficiency at the basin level is calculated by aggregating the country water efficiency using the weight-area approach. Equation 3 shows the formula to obtain the water efficiency (Rohwer et al., 2007).

$$\text{Water efficiency}_{(c)} = E_{s(c)} \times E_{con(c)} \times E_{app(c)} \quad (3)$$

Where c is at specific country in SAR, E_s is the efficiency related to the storage and intake of water, E_{con} is the efficiency related to the conduction and distribution of water, and E_{app} is related to the efficiency when water is applied through on-farm irrigation systems. Equations 4 and 5 were used to calculate the agriculture demand (AD) based on the amount of water required for irrigated and rainfed agriculture areas based on the calculated actual evapotranspiration (ETA) for agriculture, forest, pasture, and the evaporation of water bodies (the evaporation from the water bodies is very low in comparison with the ETA from the other land uses). Equation 4 describes that agriculture demand for irrigation areas is equal to ETA times the area of irrigated land divided by the water efficiency. In rainfed areas (Equation 5), the agriculture demand is equal to the ETA times the rainfed agriculture, pasture land, forest land, and area of water bodies areas.

Irrigated areas:

$$AD_{irrig(k)} = ETA_{(k)} \text{ x Area of Irrigated land}_{(k)}/\text{Water efficiency}_{(k)} \quad (4)$$

Other agriculture areas:

$$AD_{rain(k)} = ETA_{(k)} \text{ x (Rainfed crop land}_{(k)} + \text{Forest land}_{(k)} + \text{Pasture land}_{(k)} + \text{Water bodies area}_{(k)}) \quad (5)$$

The domestic demand (DD) was calculated based on the population and the water per capita consumption. The water consumption per capita in SAR is close to 50 liters per day (lpd) in rural areas and 160 lpd in urban areas, a suggested average for SAR could be 110 lpd (Kahlown, 2013). Equation 6 shows the formula used for the calculation of DD.

$$DD = \text{Water consumption per capita x population} \quad (6)$$

The industrial demand (ID) is given by the user. Table 3 shows values of water withdrawal per capita for countries in SAR for 1990 and 2025 (Seckler, 1998). The water withdrawal per capita for industrial purpose between 1990 and 2025 does not vary in most of the countries with the exception of Afghanistan. The table is used by the users to guide them with the value of C2.

Table 3. Values of Industrial Withdrawal Per Capita for 1990 and 2025 in Countries within SAR.

Country	Water withdrawal per capita (m3/year) 1990	Water withdrawal per capita (m3/year) 2025
Afghanistan	11	1
Pakistan	26	26
Nepal	2	3
Bangladesh	2	4
Sri-Lanka	10	20
India	24	24

Equation 7 shows the relation between water supply and demand using ΔS. ΔS represents all the amount of water which is part of the system that makes the supply equal to demand. ΔS considers the subsurface water, soil water content, water loss by percolation, and water in the saturated zone.

$$\text{Supply}_{(k)} - \text{Demand}_{(k)} = \Delta S_{(k)} - \text{Runoff}_{(k)} \tag{7}$$

Where runoff is the water flowing out from each basin through the rivers. ΔS, calculated by the water balance for the annual average from 1990 to 2005, is used as a constant for the water balance calculation for 2050. The assumption is water interaction in unsaturated and sutured zones below the surface level will behave similarly in 2050. Run off at the outlet of each basin is obtained from the Waterworld, and it is used as input in the water balance equation.

Calculation of the Average annual Water supply for 2050

The Climate Change Analysis was achieved based on the change of temperature and precipitation suggested by the Global Circulation Models (GCMs) of the IPCC AR5 from WorldClim (Hijmans et al., 2005). For the purpose of this paper, the Representative Concentration Pathways (RCPs) 4.5 was used (IPCC, 2014). Figure 5 and 6 show the change of precipitation and temperature proposed by nineteen IPCC AR5 GCMs for the RCP 4.5.

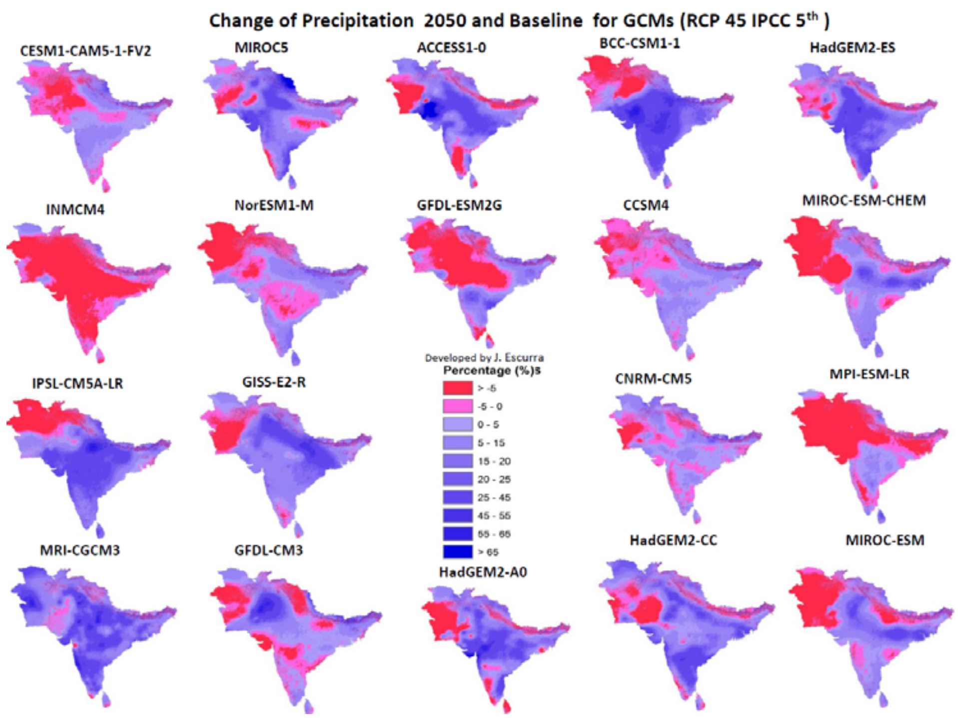

Figure 3. Change of Precipitation from Nineteen IPCC AR5 GCMS for the RCP 4.5.

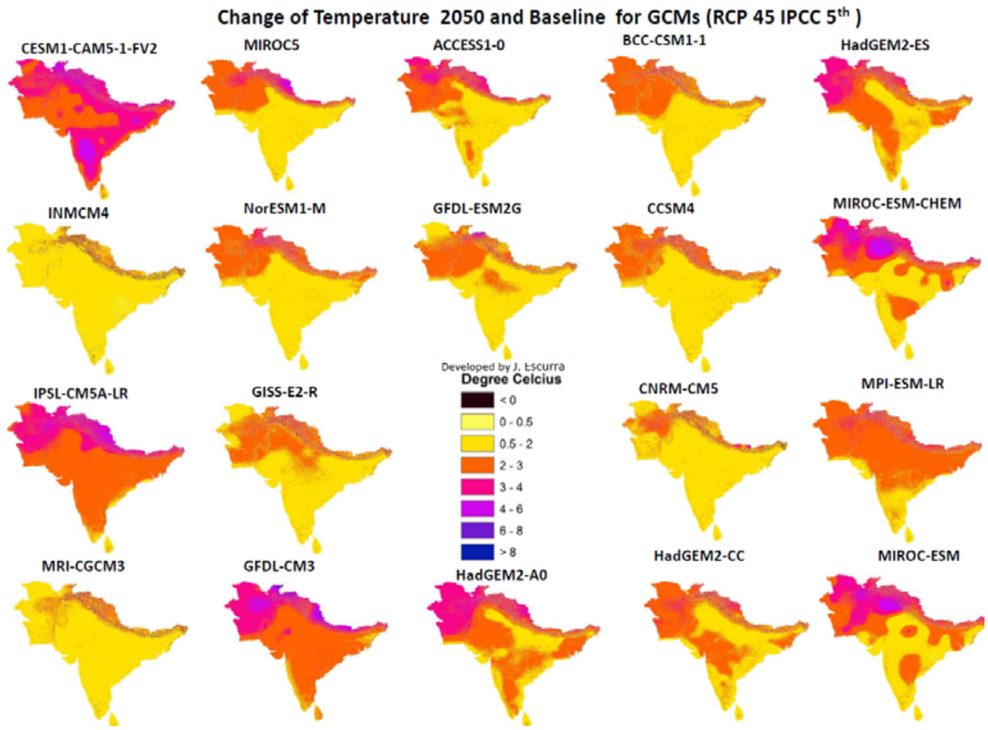

Figure 4. Change of Temperature from Nineteen IPCC AR5 GCMs for the RCP 4.5.

The change of precipitation and temperature impacts in the water supply, specifically in the precipitation and snowmelting. Increment of temperature affects the snowmelting process. It is known that increasing 2° Celsius means 3 % of increment of snowmelting (Singh and Kumar [1997]). The assumption is the glaciarized area does not vary between the relation between the 2° Celsius and 3 % increment of snowmelting is applied. However, users could modify these values based on inputs from other sources.

The change of temperature was applied using the Potential Evapotranspiration (ETP) using the Blanney and Criddle formula shown in equation 8.

$$ETP = p(0.46 \text{ x } T_{mean} + 8) \quad (8)$$

Where p is the mean daily percentage of annual daytime hours and T mean is the mean temperature (Allen at al., 1998).

Then, ETP was multiplied by the crop coefficient (Kc) to calculate the impact of the change of temperature over the ETA. Then, the gridded Kc was aggregated at basin level using the area-weight approach. Average Kc and water demand based on ETA at each basin were used as parameters to calculate the values of Kc for agriculture, forest, water bodies, and pasture at each basin. FAO proposed a set of Kc for different type of crops, pasture, water bodies (swamp), and forest (Allen et al., 1998), These proposed Kc, based on major type of crops, pasture, and forest cultivated in the basin, were also considered as input for the calculation of the values of Kc.

The domestic demand projected to 2050 was calculated based on the population in 2050 and the water consumption per capita. For the present paper, increment between the water consumption per capita from the period of 1950 to 2000 and 2050 was considered as zero. However, this value could be modified by the user. In addition, it is known (Table 2) that most of the countries of SAR industrial demand per capita will not vary from 1990 to 2025 with the exception of Afghanistan. Consequently, increment of water use for industrial between the baseline and 2050 was considered as zero. However, users could adjust this increment as well.

The overall water balance equation for 2050 considers the recalculation of runoff at the outlet of each basin. The values of runoffs for 2050, that consider the effects of population growth, climate change, and land use patterns, were calculated based on the assumption that ΔS at each basin is equal to ΔS from the period 1950 -2000.

Validation

The extend study area of the present paper, it is possible that the level of accuracy of the hydrological results is not as high, as developing a sophisticated hydrological distributed, or semi-distributed model. However, hydrologists know that developing those model at a regional level could take long time, to achieve the calibration and validation process in the entire area requires a large size of storage and memory from computers, and still encounters problems with inaccuracy can occur because of lack of information. . Developing hydrological analysis using public global datasets is the solution to develop, first assessment of analysis for investments in the water sector. Based on the results of this analysis and its validation detailed studies with more sophisticated models could be carried out to quantify in more details the benefit and cost of the investment. Following this statement, a validation process of the analysis will be described based on the comparison of the input data used from Waterworld and the results of the analysis with information from other sources (scientific papers, technical documents, and global datasets).

Figure 5 shows the comparison between the annual average precipitation and mean temperature coming from Waterworld (1950 – 2000) and climate wizard database (1951 – 2002).

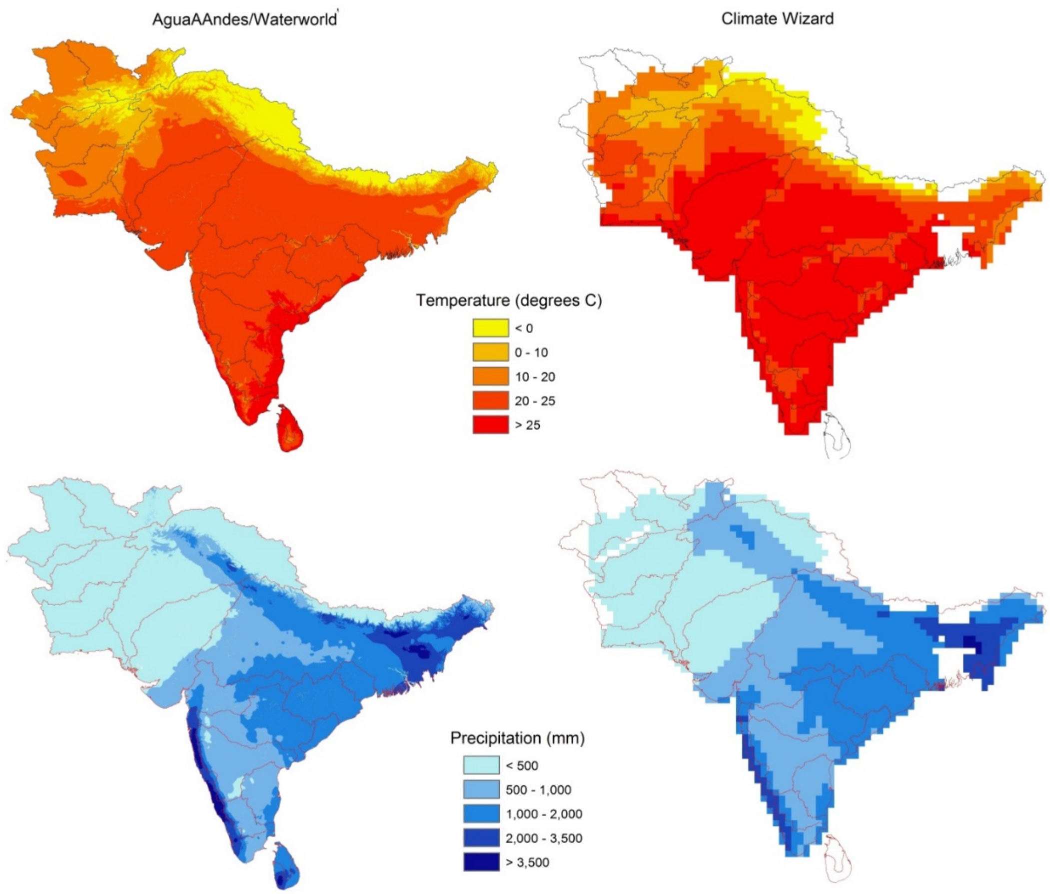

Figure 5. Comparison Between the Results (annual average precipitation and mean temperature) coming from Waterworld and Climate Wizard databases.

Figure 13 shows that there are similarities of precipitation and temperature variability between both online sources of data. It is observed that most of the area of the Bramaputra-Meghna basin has precipitation higher than 2,000 mm. On the other hand, most of the area of the Ganges basin has a predominant precipitation between 500 mm and 2,000 mm. Consequently, it is possible that the water availability situation has been unintentionally increased when both basins were analyzed as one. It is recommended that each of these basins are analyzed separately in future hydrological work.

In addition, values of annual average runoff values for eight major basins of SAR were also compared with those from other sources (scientific papers, technical report, and online database).

Table 4. Comparison of Average Annual Runoff Between Waterworld (1950 – 2000) and Other Sources.

Basin	Average runoff Waterworld (MCM)	Average runoff Other Sources (MCM)
Helmand	10,223	14,000 (Ahmad and Wasiq,2004)
Amu Darya	30,673	19,000 (Ahmad and Wasiq,2004)
Ganges - Bramaputra -	1,173,340	1,110,000 from 1993 or 1996 (FAO,2015)

Meghna		1,350,000 (Biswas, 2008)
Mahanadi Brahamani	80,864	66,640 (Sugnnan,1995) 66,880 from 1993 or 1996 (FAO,2015)
Godavari	83,997	110,540 from 1993 or 1996 (FAO,2015) 105,000 (Sarma et al., 2009)
Krishna	34,000	78,000 from 1993 or 1996 (FAO,2015) 66,000 between 1946 - 1960 (Bouwer et al., 2006) 31,000 between 1965-1979 (Bouwer et al., 2006) 21,000 between 1989-1999 (Bouwer et al., 2006)
Cauvery	18,304	21,000 from 1993 or 1996 (FAO,2015)
Indus	60,000	74,000 varies from 49,000 to 98,000 (Yu et al.,2013)

Table 4 shows that the results of runoff from Waterworld close to the range of flow proposed by scientific papers and online databases. However, there still are some differences between runoff values. Consequently, it could be helpful that hydrological and meteorological governmental entities publishes periodically official climate and runoff data on web-based repositories that allows researchers a more precise validation the information and their water resource management models. This also will positively impact in the accuracy of the public available remote sensing data (based on satellite images, interpolated and aggregated values).

RESULTS

Quantification of the water supply and demand were aggregated at the basin level. Among other results, precipitation, snow-melting, actual evapotranspiration, potential evapotranspiration, population, and surface runoff were used to classify the twenty basins within SAR. The classification was made on the concept of the identification of "hotspots" or basins with the lowest values of a Modified Water Scarcity Index (MWsci). MWsci is originated from the Water Scarcity Index (Wsci) that was developed by Asheesh (2003), Wsci compares the income water to the system (fresh water available) with all the water uses (domestic, industrial, agricultural, environmental, and water losses [i.e evapotranspiration]). Equation 8 describes how Wsci is calculated:

$$\mathrm{Wsci} = \left(\frac{\alpha}{\left(\frac{100}{100-\rho}\right)\beta e^{\theta \Delta t}(\varepsilon+\gamma+\delta)\left(\frac{100}{100-k}\right)+h+b} \right) \tag{9}$$

Where α is the annual freshwater availability, ρ is the industrial water demand in percentage depending on country structure (its value could be determined as percent of the domestic and agriculture demands), β is the population at present ($\Delta t = 0$), θ is the population growth rate calculated by ln(1+r) , Δt is the difference between future and present time, ε is the annual per capita domestic demand, γ is the annual per capita demand for green areas – this depends of inhabitation growth, δ is the annual per capita irrigation demand, h is the yearly evapotranspiration depending on basin and area, b is the annual water need for maintaining the environment, and k is the estimated freshwater losses.

The MWsci is an improved version of Wsci. MWsci incorporates the water efficiency as factor of the agriculture demand (mainly the irrigated areas) and take out the addition of water from the estimated freshwater losses (k) which was equally applied to the green areas, irrigated lands, domestic consumption. In addition, evapotranspiration (h) was took out because of double counting the green and irrigated agriculture demands. Efficiency for domestic demand is not considered because in SAR there is a large difference between the domestic and agriculture demand, so that earning from improving efficiencies does not make a substantial contribution in the regional water balance. As part of the incorporation of water efficiency within the irrigated demand, the amount of water for green and irrigated areas pass from water per capita to annual water amounts. Also, MWsci converts the industrial water demand in percentage to annual per capita industrial water demand based on table 2. Equation 10 shows the calculation of MWsci

$$\mathrm{MWsci} = \left(\frac{\alpha}{(\rho+\varepsilon)\,\beta e^{\theta\Delta t}+\gamma+\delta_{(Weff)}+b}\right) \tag{10}$$

Where α is the annual water available based on precipitation, snowmelting, and water storage, ρ is the industrial water annual per capita demand, β is the population at present ($\Delta t = 0$), θ is the population growth rate calculated by $\ln(1+r)$, Δt is the difference between future and present time, ε is the annual per capita domestic demand, γ is the annual demand for green areas, δ is the annual irrigation demand (γ and δ are calculated based on the actual evapotranspiration, δ is influenced by water efficiency), and b is the annual water need for maintaining the environment. For the case of SAR, it is assumed that b is equal to zero. The environmental demand is not considered because of the presence of intermittent rivers, however the user could modify this as well.

Figure 6 shows the values of MWsci for the major twenty basins for the baseline and 2050 considering only impacts of population growth and change of temperature and precipitation from the 19 GCMs. The land use patterns were not applied in this analysis.

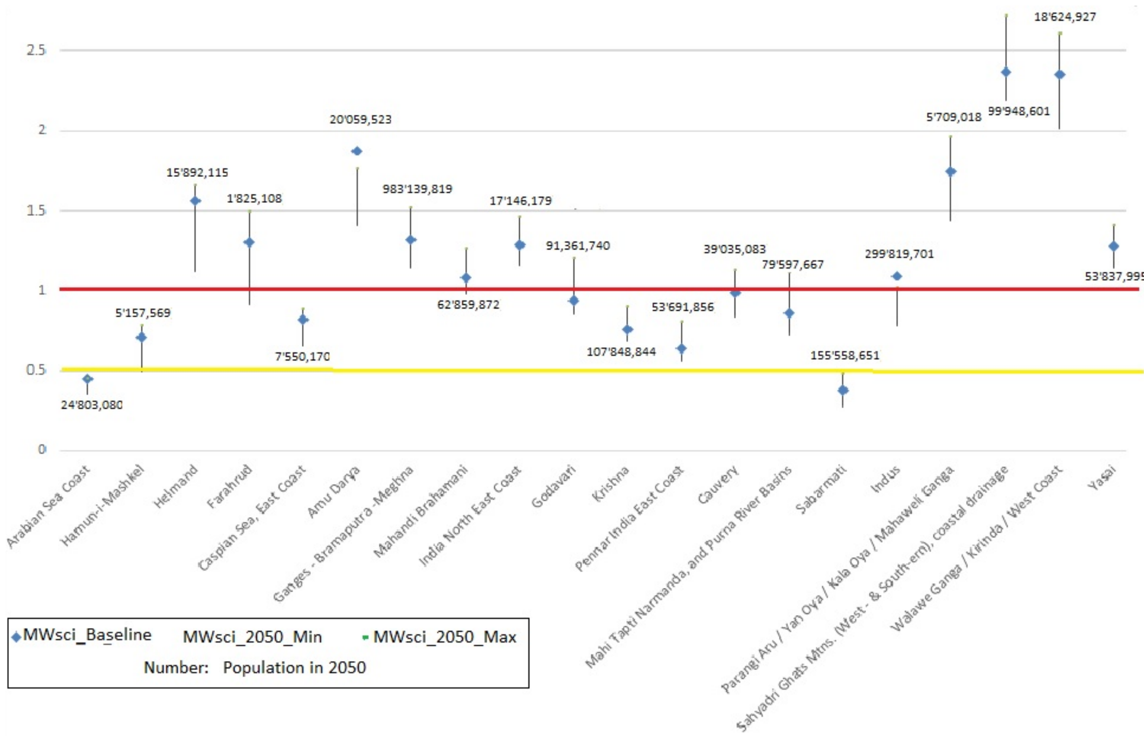

Figure. 6. Values of MWsci in Basins within SAR in 2050 Considering Climate Change Impacts and Population Growth.

Figure 7 shows the values of MW_{sci} for the baseline 1950-2000 and 2050 considering impacts of population growth, change of temperature and precipitation from the 19 GCMs, and land use pattern in the last years in each SAR country based on the information gathered in the literature review.

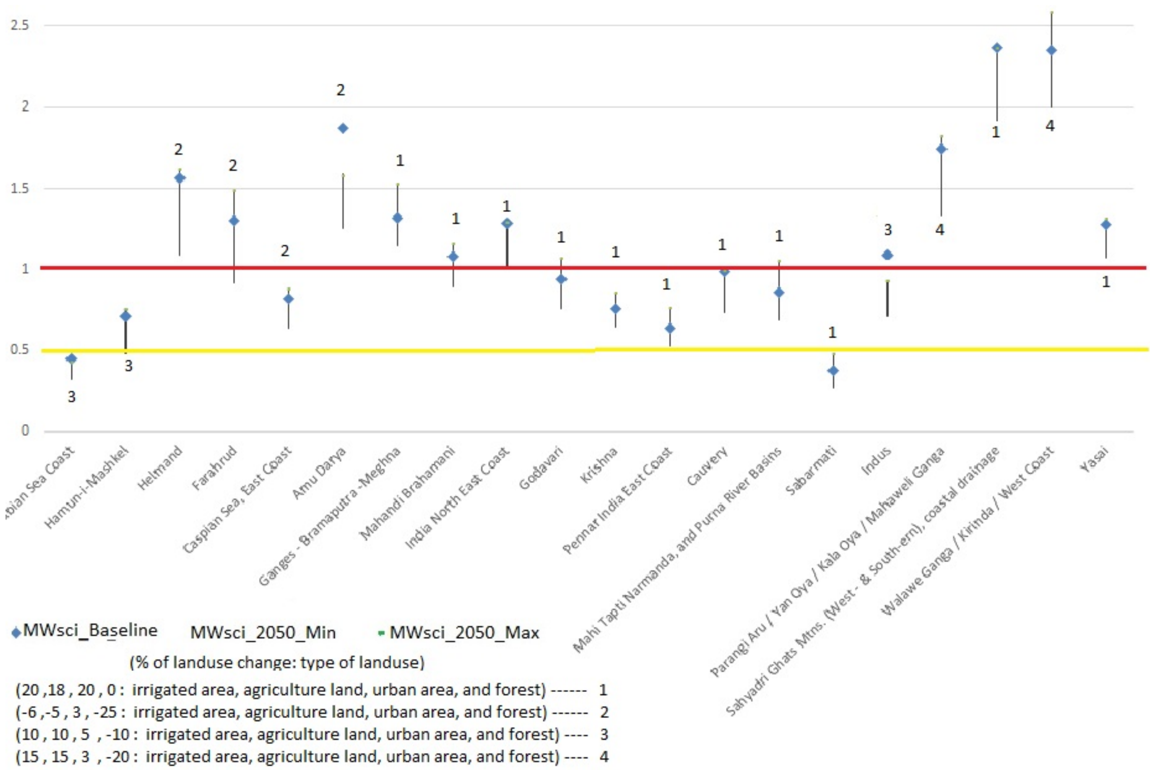

Figure 7. Values of MWsci in Basins within SAR in 2050 Considering Climate Change Impacts, Population Growth, and Land Use Patterns.

Figure 8 shows the values of MWsci for 2050 considering impacts of population growth, change of temperature and precipitation from the 19 GCMs, and landuse patterns. However, engineering work that implies improvement of the water efficiency by 10 % and increment of water storage by 30 %, has been incorporated.

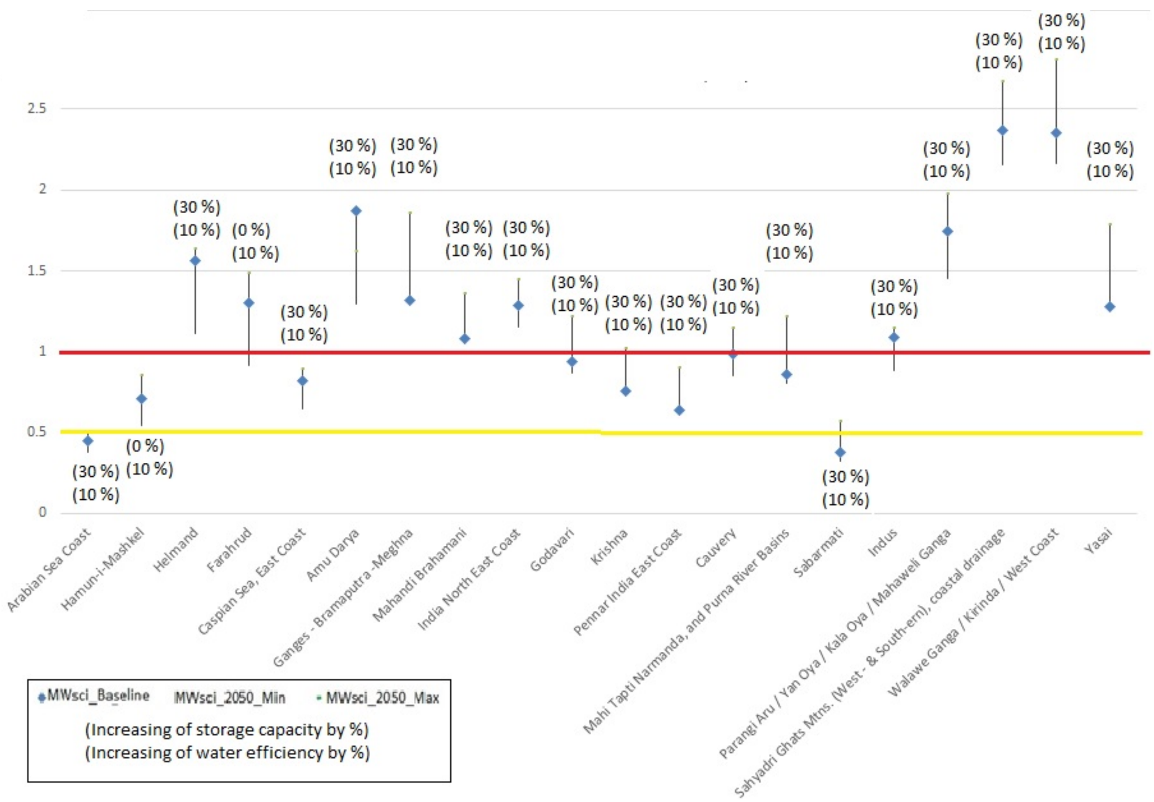

Figure 8. Values of MWsci in Basins within SAR in 2050 Considering Increment of Storage Capacity (30%) and Irrigation Efficiency (10%). Climate Change Impacts, Population Growth, and Land Use Patterns.

A scenario for 2050 that involves climate change impacts and population growth will produce different results than the same scenario with the incorporation of land use patterns based on historical data. The incorporation of the historical land use patterns intensifies the water scarcity issue in the future from seven to eight basins with values of MWsci between 1 and 0.5. Basins that have high population density and ratio irrigated area versus total area will be more impacted by the incorporation of the land use patterns. Improvement of water conveyance and on-farm irrigation efficiency (through increasing water efficiency by 10 %) and increasing storage capacity by 30 % have a direct impact in water savings. However, improving water efficiency has higher impact than increasing of water storage. In SAR, large amounts of water storage are driven by high level political decisions of the central government with (or) donors and multilateral organization investments. Irrigation conveyance and on-farm irrigation efficiency result from investments from farmers, local government, central government, multilateral organization investments, and private sector.

To better understand how the benefit of improving water efficiency will impact in closing the water gap in 2050, a Variability of Water Efficiency Index (VWeffi) is used to analyze the benefit of each specific % amount of water efficiency's increment. The VWeffi is calculated based on the equation 11:

$$VWeffi = \left(\left(\frac{Max\ Change\ of\ Runoff_{Weff\ A} - Max\ Change\ of\ Runoff_{Weff\ B}}{Weff\ B \quad Weff\ A} \right)_{(k)} \right) \tag{11}$$

Where the Max change of runoff is the maximum % of increment or decrement of runoff between the baseline (1950 – 2000) and 2050. As described, climate change impacts from 19 GCM's inputs were incorporated in the model, and the maximum value of % of change between the baseline and 2050 was used for each value of water efficiency. The water efficiencies values simulated in this analysis were the current water efficiencies plus 5%, 10%, 15%, 20%, 25%, and 30%.

Using an objective function (Equation 12) basins that need irrigation investments to confront the problems of water scarcity in 2050 are chosen:

$$BSii = \frac{\left(\frac{MWsci_{max} + MWsci_{min}}{2} \right)_k (\phi) + (VWeffi_{5\%} - VWeffi_{30\%})_k (\infty)}{\phi + \infty} \tag{12}$$

Where BSii represents the basins that are facing water scarcity and improving water efficiency will strongly impact as part of the solution, MWscimax and MWscimin are respectively the maximum and minimum modified water scarcity indexs, VWeffi is the index for increment of 5 % and 30 %, ϕ is a weighing factor equal to 0.58, and ∞ is a weighing factor equal to 0.42.

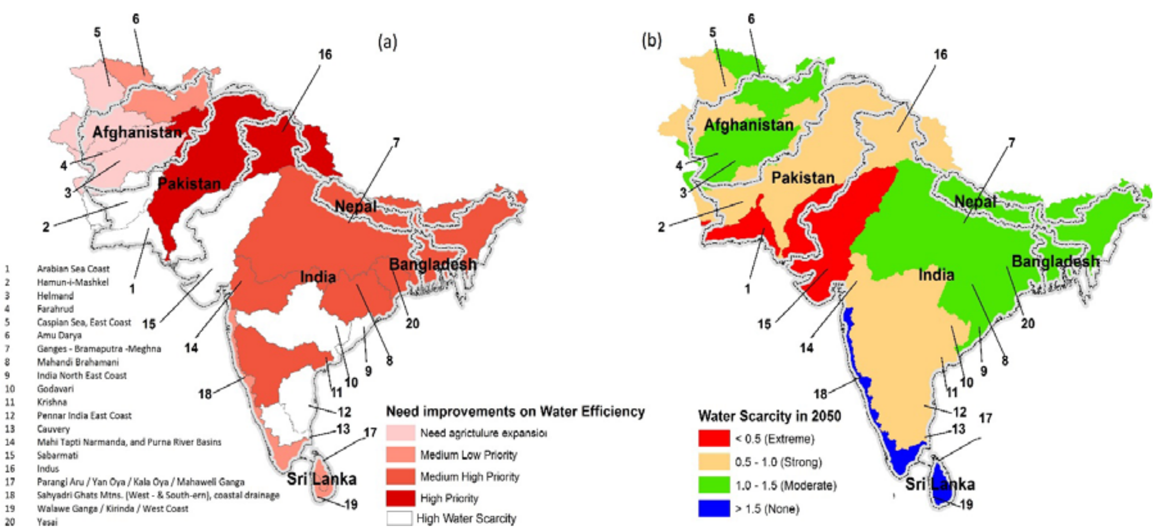

Figure 9(a), and (b). Basins that Need Improvements on Water Efficiency (BSii) and their Levels of Water Scarcity (MWsc) for 2050.

Figure 9(a) shows the basins that need improvements on water efficiency as main action to confront water scarcity in 2050 based on the calculation of the BSii. Basins, which will face extreme and extreme-strong water scarcity, have not been considered in the calculation. Because of the complicated water availability situation in 2050 within these basins, any action that will enhance water management (i.e improving water efficiency) need to be applied without any restriction. Figure 9(b) shows the level of water scarcity in 2050 for the basins in SAR based on the calculation of MWsc. Basins that need irrigation investments on improving water efficiency to confront water scarcity in 2050 are: (i) Indus; (ii) Ganges-Bramaputra-Meghna; (iii) Yasai; (iv) Mahandi Brahamani; (v) Krishna; and (vi) Mahi Tapti Narmanda and Punar River. The basins that could face extreme water scarcity in 2050 are: (i) Arabian Sea Coat; and (ii) Sabarmati.

CONCLUSIONS

The "hot spots" for irrigation investments in South Asia are: (i) Indus; (ii) Sabarmati; (iii) Arabian Sea Coast; (iv) Caspian Sea East Coast; (v) Godavari; (vi) Pennar India East Coast; (vii) Krishna; and (viii) Cauvery. Caspian Sea East Coast, Helmand, and Farahrud are basins in which expanding the irrigated area will have better impact as first action than improving water efficiency. Benefit of water efficiency is related to the relation of the irrigated area with the total green area (includes forest, pastured, and rainfed agriculture land). Ganges-Bramaputra-Meghna is not considered a hot spot because it will not face serious problems of water scarcity in 2050. Now, the results could be different if Ganges was analyzed separately from Bramaputra that concentrates high amount of precipitation. In addition, it is concluded that improving water efficiency is more effective on reducing the water gap in 2050 than increasing the water storage capacity. This conclusion was reached comparing the water balance results from incrementing a percentage of the water storage and water efficiency in all the basins. Developing hydrological model, which analyzes impacts of climate change, population growth, and land use pattern, produces results with more water deficit than those produced by hydrological model that does not consider land use change. It is important to clarify that the WASD-PUB model is a Macro-Excel spreadsheet that uses an input georeferenced public domain information which is not the same as data gathered in the field. Therefore, WASD-PUB should be used to aid experienced practitioners in the field to undertake initial screening options at a pre-feasibility level, and further analysis (using scientific papers, technical documents) needs to be carried out as part of the validation process of the results. So far, the validation process carried out for the present paper indicates that the results are similar to other authors.

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EXAMPLES OF REMOTE SENSING TO SUPPORT ADVANCED WATER MANAGEMENT

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ABSTRACT

Remote sensing techniques to improve estimates of irrigated area and actual crop evapotranspiration (ET) have become a valuable tool to support agricultural water management. Examples of the use of remote sensing over the past decade to support advanced water management are presented, focusing on quantification of irrigated area and quantification of actual ET. These techniques, applied at scales from individual fields to entire regions can provide multiple benefits. Mapping of irrigated area supports evaluation of drought impacts and expansion of irrigated area over time. Estimation of actual evapotranspiration based on satellite data supports accurate quantification of historical actual water use, which when combined with supporting analyses, enables estimation of total applied water required to meet actual irrigation demands including groundwater pumping and net depletion of groundwater for areas reliant wholly or in part on groundwater for irrigation. These kinds of retrospective analyses are foundational for identifying and assessing water conservation and water management opportunities at the farm and water supplier levels.

In addition to the description of specific examples of these applications, observations based on past and ongoing experience applying remote sensing techniques are discussed. The application of remote sensing technology can clearly enhance knowledge of actual conditions, but also requires careful implementation and rigorous attention to quality control to maximize accuracy and usefulness of results. To maximize knowledge gained through remote sensing requires bridging the gap between the "eye in the sky" and reality on the ground.

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APPLICATION OF SONTEK ADVM'S IN WATER DISTRIBUTION MANAGEMENT FOR IRRIGATION SYSTEMS

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ABSTRACT

The efficient management of water distribution in irrigation networks is highly dependent on accurate real-time flow information throughout a canal network. The traditional flow monitoring methods used in most irrigation networks consists either of a weir or flume design each with its own challenges in construction, operation and maintenance requirements. The common impacts of all measurement structures on canal networks are the increased capacity required due to hydraulic effects, accumulation of sediment and aquatic vegetation in the upstream pool, measurement accuracy affected by change in flow conditions downstream and the increased demand for water supply that exceeds the measurement structure capacity.

SonTek developed Acoustic Doppler Velocity Meters (ADVM) specifically for the application in irrigation canals, drainage canals, storm water canals and pipes with the objective to produce accurate and reliable flow measurements, reduce the overall impact on existing canal infrastructure, installation and operation must be simple and the ability to relocate instrument to areas of high demand if required.

The ADVM's are a highly adaptive measurement platforms capable of measuring in all canal designs with the ability to adjust measuring parameters based on the water depth to give the user an increase measurement accuracy during low flows conditions. The internal flow calculation is based on either the "Integrated Velocity" or "Velocity Index" method depending on the accuracy requirement by the user.

The instrument internal flow calculations and ability to transmit flow measurements with telemetry give the user the management tools to accurately and efficiently manage water distribution network. The expansion of Acoustic Doppler instrumentation applications within the different facets of Irrigation is showcased in this presentation and highlights the versatility of the technology and the capability of SonTek Acoustic Doppler instruments in flow measurements.

INTRODUCTION

The efficient management of water distribution in irrigation networks is dependent on accurate real-time flow information, especially where canal networks are operated to full capacity or to accommodate for additional water allocation in existing canal network. The actual cases discussed in this paper highlights the applicability of Acoustic Doppler Velocity Meters (ADVM) in the management of water distribution with the focus on

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dynamic hydraulic and flow conditions that exists in artificial canals and the requirement of additional discharge monitoring points where lack of infrastructure makes it not feasible to efficiently management water resources.

The versatility of SonTek ADVM's is demonstrated during these discussions and it is highlighted that current methodology and technology available in open channel flow monitoring does not surpass the application range, accuracy and cost effectiveness of the SonTek ADVM series.

The paper demonstrates that SonTek ADVM instrument range can be used in conjunction with current monitoring stations or stand alone in producing real-time flow information for accurate and reliable management of water distribution in irrigation networks.

APPROACH

Monitoring Limitations

Continuous flow monitoring and affective management of water distribution in irrigation networks are mostly affected by increased water demand, lack of maintenance and or lack of monitoring infrastructure. These factors can have significant impact on the data accuracy and as a result affecting the overall operations.

Increased Demand. Increased water demand within the existing irrigation network are normally ascribed to the increase of cultivated land and this a common phenomenon at all irrigation schemes. The operating capacity of canal networks are based on the original flow requirements and in most cases the canal networks are operated equal or above the maximum flow capacity to accommodate the additional flow.

The increased flow requirements within an existing canal network can have significant impact on the accurate monitoring of flow at gauging weirs such as the following weir types due to submergence that occurs downstream of the weir.

- V-Notch
- Cipolletti
- Parshall Flumes
- Broad-Crest Weir
- Sharp-Crest Weir
- Triangular Profile Weirs

Figure 1. Triangular Profile Weir (Orange-Riet Canal at Scheiding, South Africa))

Submergence is caused by either increased water level downstream due to hydraulic structures, increased water supply within existing canal network, lack of maintenance on canal network or combination of above. This impact the applicability of the gauging weir as a controlling feature within the canal and the numerical discharge equations developed for each specific gauging weir design.

Lack of Maintenance. The lack of maintenance on irrigation network infrastructure impacts on the accuracy and reliability of flow monitoring in either concrete lined or earth canals. Sediment transport and vegetation are the two major factors impacting on the measurement accuracy of gauging weirs, ADVM's and other discharge measurement devices.

The impact of gauging weirs are multi fold due to the damming effect is it creating in the canal network, preventing any material to be transported downstream to be discharged directly in either drainage canals or river systems. The damming effect of gauging weirs creates sediment deposition directly upstream of the weir and this reduces the cross section area upstream of the weir and as a result the approach water velocity towards the weir is increased. This phenomenon can impact the applicability of numerical discharge equations developed for the gauging weir. The sediment is also creating conducive environment for aquatic weeds that further impacts the discharge measurement accuracy and maintenance requirements.

Lack of Infrastructure. The lack of infrastructure in existing canal network makes it difficult to efficiently manage water distribution within a canal network. This is further amplified by the fact that the implementation of a new discharge monitoring point or changes to existing monitoring infrastructure is dependent of available resources and scheduled maintenance programs.

The complexity of the design and construction process of gauging weir is dependent on the type of gauging weir with the following main points that need to be highlighted.

- Gauging weir act as controlling feature in the channel
- Height of notch above canal floor and this will be dependent on the percentage of submergence that can be handled by numerical formulas without any correction.
- Flank walls required in the design of the gauging weir? In figure 1, the V-Crump numerical discharge equation is based on vertical flank walls on both banks of the canal. The requirement of flank walls is dependent on the gauging weir type.

The management of water distribution for irrigation purposes are not limited to artificial canals but are also applied to river systems within the irrigation scheme management area. Control structures or weirs are typically used for regulation of water distribution downstream for irrigation. The complexity of construction work in natural channels requires significant resources in establishing new discharge monitoring points or variations to existing infrastructure.

In the Riet River, South Africa a weir consisting of a Sharp-Crest gauging weir was used to manage water distribution in the lower parts of the irrigation scheme management area. In normal flow conditions the discharge is monitored from the flow over the Sharp-Crest gauging weir, however during peak demand water is released through the scour pipes for irrigators downstream of the main weir in Figure 2 (Riet River at Zoutpansdrift). This method was adequate in supplying the required flow downstream, however controlling and monitoring the process was ineffective.

Figure 2. Main weir (Riet River at Zoutpansdrift, South Africa)

Outlet structure in Figure 3 was constructed downstream of the main weir to release required flows based on demand and more importantly the ability to monitor and manage the water distribution downstream of the main weir.

Figure 3. Outlet structure (Riet River at Zoutpansdrift, South Africa)

Case Studies

The case studies discussed in this paper will show the applicability of SonTek ADVM instruments within Irrigation operations and how it can be applied to overcome the current limitation in the monitoring requirements for water distribution.

Scheiding - Canal. The Orange-Riet Canal at Scheiding monitoring site is situated downstream of the Scheiding pumping station from where water flows 112km in the Scheiding canal to a network of smaller canals for irrigation in the Riet River catchment. The monitoring site is the first monitoring point in the irrigation network and therefore high accuracy is required in determining the total discharge from the pump station.

The increase in demand and additional abstraction points downstream in the canal has impacted on the applicability of the gauging weir as a controlling feature in the canal. The variation in flow conditions at the gauging weir changed the ratio between upstream and downstream water levels and as a result impacted the applicability of numerical discharge equation of the weir during certain flow conditions.

An ADVM instrument in Figure 4 was installed downstream of the gauging weir and similar to gauging weir requirements; the site selection was based on number of site requirements based on number of hydraulic principles.

- Steady Uniform flow conditions
- Sub Critical flow conditions.
- Drawdown zone at section controls should be excluded from the effective measurement volume. The drawdown zone is defined by the distance from the crest of the control to a point upstream.
- Straight length of channel with uniform cross-section and slope (10 times section width).
- Uniform velocity distribution over the width of the cross-section.
- Approach velocities with Froude number ≈ 0.5. The flow in the approach channel should be smooth and free of disturbances.
- Unsteady flow and backwater conditions are acceptable within the affective measurement volume, though the user need to determine if a stable and well-defined relationship is viable between the Measured Velocity and the computed Mean Velocity (ONLY relevant to Index Velocity method).
- Artificial controls upstream of monitoring site could cause turbulent and unsteady flow conditions and should be located far enough upstream.
- Hydraulic structures upstream could cause turbulent and unsteady flow conditions and should be located far enough upstream.
- Bends upstream of monitoring site could create skew flows at the point of measurement and should be located far enough upstream.
- Steep slopes upstream of monitoring site could cause turbulent and unsteady flow conditions and should be located far enough upstream.
- Roughness of the channel bed and banks must be investigated at the site to determine what impact it will have on the velocity distribution
- Avoid prominent obstructions in a pool that can affect the velocity pattern.
- Discharge sensitivity towards the channel section
- Aquatic plants can affect the ADVM operation and areas where excessive aquatic plants are present should be avoided.
- Sediment deposition or scouring can affect the ADVM operations and areas where excessive sediment transport occurs should be avoided.

Figure 4. ADVM Installation (Orange-Riet Canal at Scheiding, South Africa))

The ADVM instrument was configured with “Stage Area” rating and “Index Velocity” rating. The “Stage Area” rating is based on the cross section that is in line with the instrument and a relationship was developed cross sectional area calculated from each stage increment. The “Index Velocity” rating is relationship between the mean channel velocity and the velocity measured by the ADVM instrument.

Measurements were performed with the ADVM in conjunction with discharge measurements at the gauging weir upstream with calculated daily average flows of both the ADVM and gauging weir plotted in Figure 6. The data shows that there are difference in daily average flows from September 2014 to February 2015 between the ADVM and gauging weir. During the calibration of the ADVM with discharge measurements with Acoustic Doppler Current Meter (ADCP) it was found that due to the increase in submergence at the gauging weir, the flows were overestimated. To compensate for the additional submergence at the gauging weir water level sensors were installed downstream of the gauging weir in Figure 5 to determine the actual submergence. The additional stage measurements were incorporated in the numerical discharge equations of the gauging weir to compensate for submergence influences. The data recorded from March 2015 to May 2015 in Figure 6 shows a much closer trend between the ADVM and gauging weir after correction is applied for submergence.

Figure 5. Downstream Measurement (Orange-Riet Canal at Scheiding, South Africa)

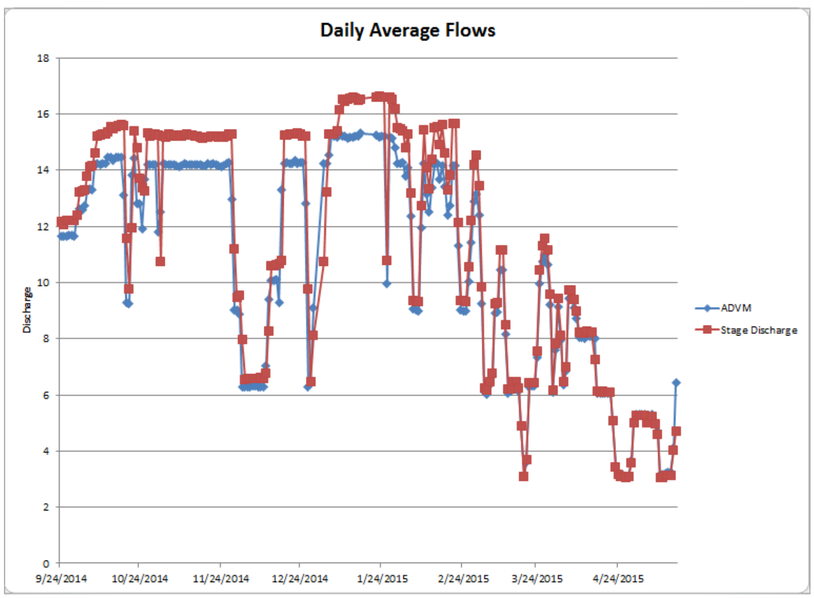

Figure 6. Daily Average Flows (Orange-Riet Canal at Scheiding, South Africa)

Plant1 - Canal. The accurate measurement of discharge in dynamic flow conditions can be a complex process and a as result downstream influences such as hydraulic structures, vegetation and or sediment deposition can have significant impact on the accuracy stage discharge ratings. The impact of downstream influences on stage discharge relationship will result in most cases overestimating the flow at a specific monitoring location.

SonTek ADVM instruments ability to measure in dynamic flow conditions are based on the “Index Velocity” developed from Measured Velocity. The Index Velocity Rating principle is based on a stable and well-defined relationship between a Measured Velocity and the computed Mean Velocity. Mean Velocity is calculated from the total discharge and the submerged area within the channel section. The relationship between the Measured Velocity and Mean Velocity is a function of the velocity profile, cross-stream velocity, velocity distribution and stage. The relationship in its simplest form can be written with the following variables as a function,

$$V_m = a + V_I b \tag{1}$$
$$V_m = a + V_I(b + cH) \tag{2}$$

The relationship of the velocity component for the Index Velocity Rating can be accurately defined by the X component of the Measured Velocity in ideal flow conditions. Ideal flow conditions seldom occur in natural or artificial channels and for this reason SonTek has developed a range of Index Velocity Types based on actual flow conditions measured with ADVM instruments. The Index Velocity Types available allows the user to determine,

- the index velocity that best define the relationship with Mean Velocity
- other velocity components that may impact the relationship with Mean Velocity

The integrated (theoretical) velocity for open channel and pressure (pipe) flow are based on the Measured Velocity from the ADVM and Theoretical Flow Principles. The Measured Velocity is applied with Theoretical Flow Principles to develop an integrated velocity across the submerged area within the channel section.

The Integrated Velocity method for open channel and pressure (pipe) flow is dependent on ideal flow conditions due to the following key factors,

- The methodology applied in developing integrated velocity is based on Theoretical Flow Principles,
- Flow conditions are steady uniform flow.
- The flow regime is subcritical.
- ADVM is positioned in the channel section where the maximum velocity occurs.

The development of accurate mean integrated velocity will be significantly impacted if the flow conditions do not comply with the above mentioned factors. The application of the integrated velocity method for discharge calculation is not applicable to all flow conditions and the user need to perform comprehensive evaluation of the site conditions and other factors that may impact on the ADVM measurement accuracy. Depending on the monitoring objectives and site conditions, the Index Velocity Method could be the preferred method over the Integrated Velocity method for discharge calculations.

IQ Plus instrument was installed at Plant 1 in Figure 7 to validate the applicability of the instrument as an accurate monitoring platform in dynamic flow conditions. The canal reach selected for the flow monitoring verification had a number of conditions that were conducive to dynamic flow conditions,

- No control feature in canal
- Vegetation on both banks

Figure 7. IQ Plus Installation (Plant 1, LCRA)

Figure 8. Impact of vegetation on Flow (Plant 1, LCRA)

The validation process consisted of the development of index velocity as described previously in the paper. Calibration measurements were performed during the index velocity process to verify the rating development. During the instrument validation it was decided to compare the index velocity developed against the integrated (theoretical) method discharge calculations.

The discharge calculations shown in Figure 9 shows that there are good relationship between the discharge calculated form index velocity versus integrated method. It is important to note that the integrated method is based on theoretical principles and that there are a number of hydraulic requirements that need to be adhered to in applying this method. The integrated method is a quick and cost effective solution in determining the discharge at any given time and if higher accuracy is required, the index velocity must be applied.

The application of index velocity method requires more resources to develop and maintain and the following aspects need to be taken into account for this,

- Additional data collection and processing
- Hardware such current meter or ADCP instruments

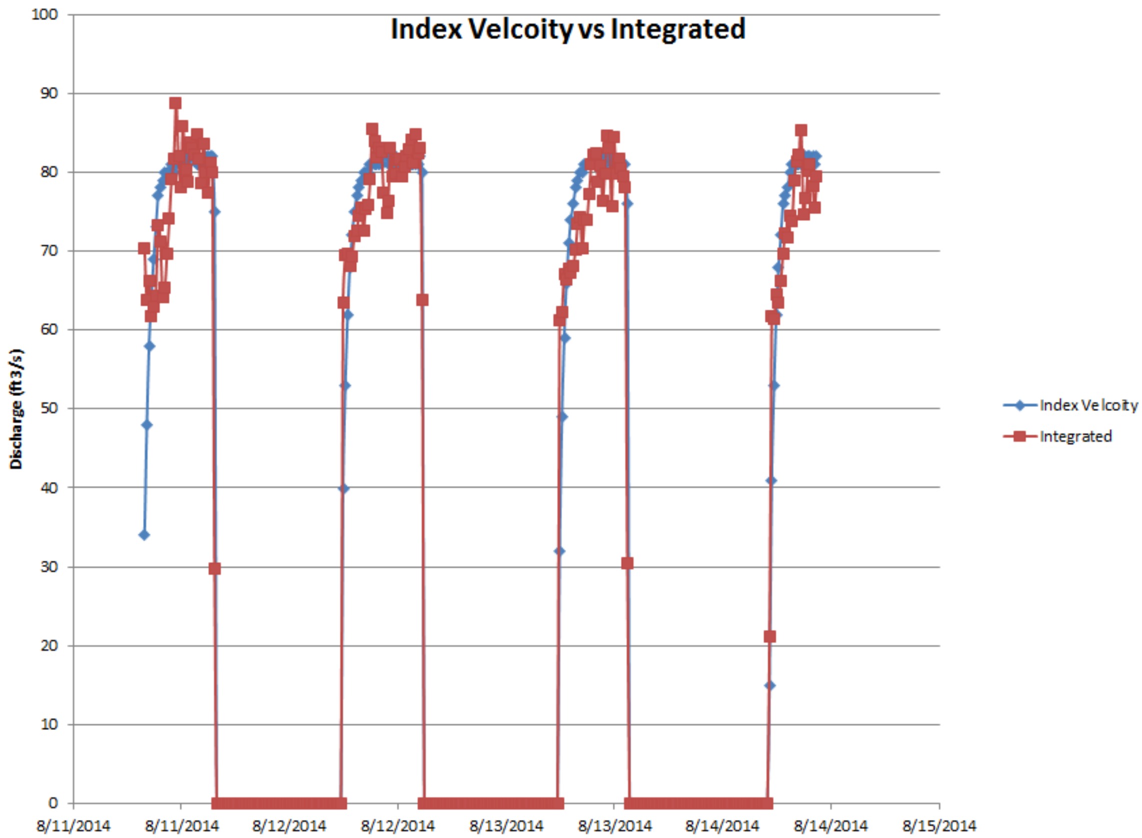

Figure 9. Index Velocity vs Integrated Discharge (Plant 1, LCRA)

<u>USGS – ADVM Installations</u>.

The USGS has approximately 470 monitoring stations in natural channels that are equipped with ADVM's using the velocity index method to calculate discharge. The ADVM's are installed at monitoring sites where complex flow conditions exists that requires extensive level of resources to develop a normal stage discharge relationship and the following flow conditions are present at these monitoring sites,

- Tidal affects,
- Variable backwater,
- Highly unsteady flow.

The application of ADVM in natural rivers for discharge measurement by the USGS and other major agencies is indication that ADVM is a viable and accurate solution in the measurement of discharge, especially in complex flow conditions.

CONCLUSION

The application of Acoustic Doppler Velocity Meters (ADVM) in artificial or natural channels as a platform for continuous discharge measurements is a viable option for Water Distribution Management. SonTek ADVM instruments in relation to gauging weirs or other technology in discharge measurement are cost effective and the implementation process is straight forward.

The advantage of ADVM technology over traditional gauging weirs is the installation and configuration requirements. The construction of gauging weirs need to be incorporated in the maintenance schedule and is normally performed during one of the dry periods. ADVM instruments can be installed and operational within 8 and therefore the interruption to normal operations is minimal. ADVM instruments are ideal to be used in conjunction with existing monitoring network especially where the current infrastructure maximum capacity is reached and as a result the measurement accuracy is affected.

SonTek ADVM's series in Figure 10 and 11 has two methods of discharge calculations and are based on the index velocity and integrated methods. The two methods of discharge calculations are unique as described previously in the paper. The application of each method is dependent on the user accuracy requirements and available resources.

Figure 10. SonTek SL15003G and SL30003G

Figure 11. SonTek IQ Standard and IQ Plus

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- Kevin, Ulrich, Lower Colorado River Authority, USA: Plant 1

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WATER AND NITROGEN REQUIREMENTS OF SUBSURFACE DRIP IRRIGATED POMEGRANATE

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Rebecca C. Phene[3]

ABSTRACT

Surface drip irrigation is a well-developed practice for both annual and perennial crops. The use of subsurface drip is a well-established practice in many annual row crops, e.g. tomatoes, strawberries, lettuce. However, the use of subsurface drip on perennial crops has been slow to develop. With the on-going drought, interest has increased for use on both annual and perennial crops because of the ability to improve water productivity and reduce applied water. Pomegranate acreage is California is approximately 25,000 acres. However, there is very little information about the water and nutrient requirements of the crop. We developed a replicated trial to determine the water and nutrient requirements of a maturing pomegranate crop being grown with surface and subsurface drip irrigation. The system is controlled by a weighing lysimeter that irrigates both systems when 1 mm of crop water use has been measured. Nitrogen fertilizer is injected with the irrigation water at 50%, 100%, and 150% of what is considered adequate for the N needs of the crop. The marketable yields were 15.7 and 14.8 t/ac for the SDI and DI respectively in 2013 and 21.2 and18.1 t/ac in for the SDI and DI in 2014. The water use efficiency was higher in the SDI plots compared the DI plots in both years. The applied water in 2014 was 31 inches in the SDI treatments and 33 inches in the DI treatments. Applied nitrogen ranged from 55 to 305 lbs/ac over 2013 and 2014.

INTRODUCTION

The California Department of Water Resources (DWR) Bulletin 160-05 states: “In the future, water management challenges will be more complex as population increases, demand patterns shift, and environmental needs are better understood…”. The competition for water will increase as the population of California increases to nearly 50 million people by 2050 and the environmental flows will increase to meet the demands in the Sacramento San Joaquin Delta. California agriculture is facing severe, recurring water availability shortages, groundwater quality deterioration, and accumulation of salts in the shallow, perched water table. To compensate for the lack of sufficient surface water, growers on the west side of the San Joaquin Valley are pumping from deep saline aquifers, bringing salts to the surface that are causing drainage issues and irrigated acreage to be drastically reduced. Senate Bill (SBX 7-7) was enacted in January 2012 and will require irrigation districts to measure delivery of water to growers by July 2012. A

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recent University of California Davis report on groundwater quality released on March 13, 2012 and entitled: "Nitrate in Drinking Water Raises Health Concerns for Rural Californian" indicated that "one in ten people living in California's most productive agricultural area is at risk of exposure to harmful levels of nitrates contamination in their drinking water". Laws on groundwater quality will soon be enacted controlling leaching of agricultural NO_3-N to the groundwater.

Research and demonstration have demonstrated that well managed surface drip (DI) and subsurface drip irrigation (SDI) systems can eliminate runoff, deep drainage, minimize surface soil and plant evaporation and reduce transpiration of drought tolerant crops. Reduction of runoff and deep drainage can also significantly reduce soluble fertilizer losses and improve groundwater quality. The success of DI and SDI methods depends on the knowledge and management of fertigation, especially for deep SDI. Reductions in wetted root volume, particularly if combined with deficit irrigation practices, restrict available nutrients and impose nutrient-based limits on growth or yield. This is particularly important with an immobile nutrient such as phosphorus (P). Avoiding nutrient deficiency or excess is critical to maintaining high water and fertilizer use efficiencies (WUE & FUE). This interaction has been demonstrated for field and vegetable crops (Ayars, et al. 1999) but no similar research has been conducted for permanent crops.

Pomegranate acreage in California is now about 28,900 ac and Kevin Day, UC Farm Advisor, noted that "from 2006 to 2009 the area planted with pomegranate trees has increased from approximately 11,800 ac to 14,800 ac in 2006 to 28,900 ac in 2009" (Personal communication K. Day, 2009). The rising demand for juices, e.g. pomegranate, blueberry, with healthy bioactive compounds, mineral nutrients and high antioxidant contents are partially contributing to this growth in acreage. Pomegranate is thought to be both a drought and salt tolerant crop that can be grown on saline soils and is thus ideally suited for the Westside of the San Joaquin Valley as a replacement for lower value crops.

There have been no studies that evaluated the water and fertilization requirements of developing pomegranate orchard using either surface drip or subsurface drip irrigation. We will describe the results of the last 2 years of a project that is characterizing the water and nitrogen requirement of a recently planted (2010) pomegranate orchard.

MATERIALS AND METHODS

This project is located on the University of California Kearney Agricultural Research and Extension Center (KARE) and uses a 3.54-ac pomegranate orchard (*Punica granatum, L* var. Wonderful) that includes a large weighing lysimeter (Fig. 1) (Phene et al. 1989) Trees were planted with rows spaced 16 ft. apart and trees in the rows spaced 12 ft. along the row. The orchard is laid out in a complete randomized block with sub-treatments and 5 replicates.

A plot consists of three rows of trees with a minimum of 7 trees in length. The center row is used as the experimental row with the center 5 trees being used for sampling. The lysimeter is used to determine the water use for the fully irrigated (100%) subsurface drip irrigation with adequate nitrogen treatment and to automatically manage the hourly irrigation scheduling on the site. Water applied to the surface drip treatments is increased by 10% over the SDI treatment to account for evaporation from the soil surface and water used by weeds. The lysimeter tree is irrigated using a SDI system with the same number of emitters per tree as the rest of the orchard. All flow is measured by flow meters for each of the treatments.

The main irrigation treatments are surface drip (DI) and subsurface drip (SDI) (installed at 20-22-in depth) systems with dual drip irrigation laterals, each 3.5 ft. from the tree row. The drip system uses 2 L/hr in line emitters spaced at 3.3 ft. The fertility treatments are 3 N treatments 50% of adequate (N1), 100% of adequate (N2) and 150% of adequate (N3), based on biweekly leaf tissue analysis. The fertilizers are all applied by variable injection of N-pHURIC (10% N as urea, 18% S), AN-20 (10% NH_4-N and 10% NO_3-N). Potassium thiosulfate (K_2T, 25% K from K_2O and 17% S) and phosphorus (from H_3PO_4, PO_4-P) are supplied by variable injection of P=15-20 ppm and K=50 ppm to maintain adequate uptake levels. The pH of the irrigation water is automatically maintained at 6.5+/-0.5. Flow and concentration of fertilizers are measured.

With the concern for transport of nitrate to the groundwater it is essential to characterize the movement of NO_3 through and below the crop root zone. We did this by calculating the soil matric potential gradient through the root zone. We used heat dissipation soil water matric potential (SMP) sensors (Campbell Scientific Inc. CSI-229) calibrated at 25° C at pressure ranging from 10 to 150 kPa to measure the soil matric potential. These SMP sensors were installed in two columns of 4 SMP sensors each at depths of 24 in. (0.6 m), 36 in. (0.9 m), 48 (1.2 m) and 60 in.(1.5 m) from the soil surface. These SMP's provide the SMP status in the lysimeter and are used to calculate the hydraulic gradient to infer the leaching potential under high frequency SDI (Phene et al., 1989).

Fruit yield was determined from the trees in the experimental row. Statistical analysis was done by Dr. Bruce Mackey, ARS Biometrician.

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RESULTS

The yearly cumulative grass reference ET (CIMIS ET_o) and the orchard evapotranspiration (ET_c) measured hourly by the weighing lysimeter were used to develop the irrigation requirement and crop coefficient for maturing pomegranate. The crop coefficient (K_c) and the 5th order polynomial regression of the daily K_c were developed for grower's use.

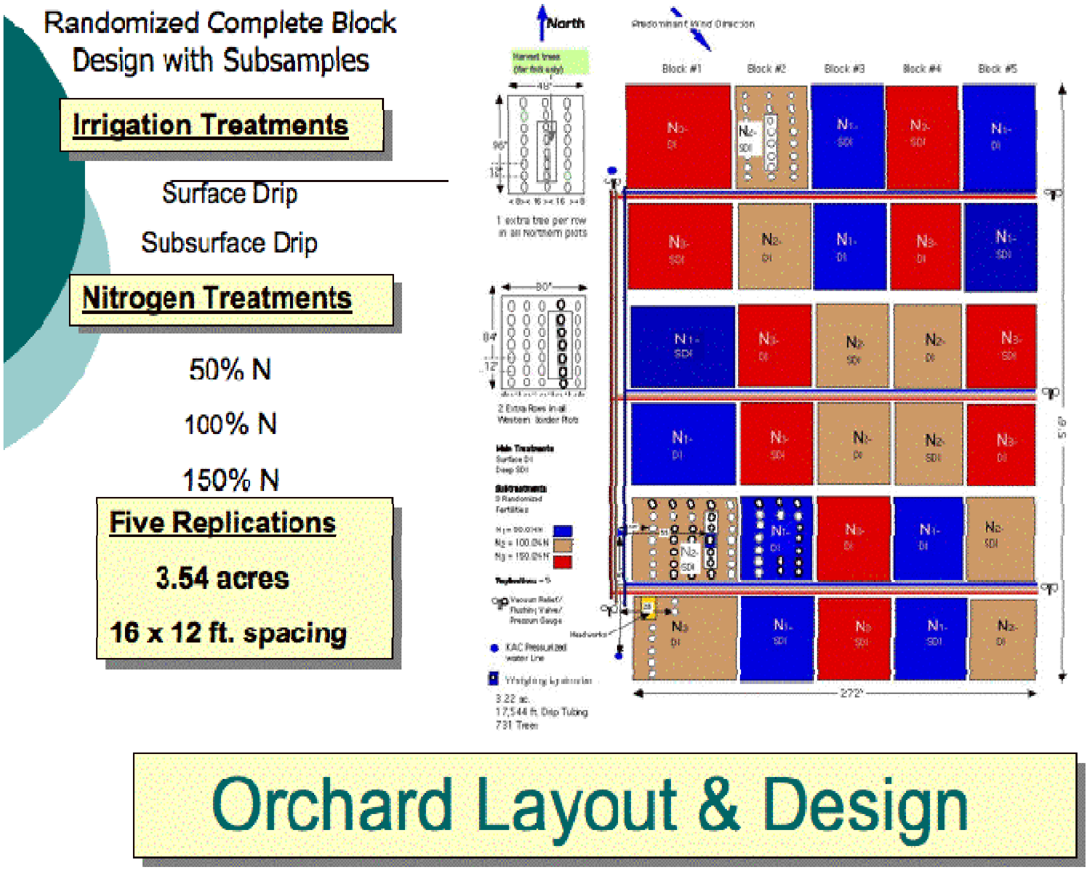

Figure 1. Orchard treatment, design and layout for surface drip irrigated (DI) and subsurface drip irrigated (SDI) pomegranate located on the Kearney Agriculture Research and Extension Center.

The 5th order polynomial regression of the crop coefficient (K_c) is $K_c = 3e^{-10} x^4 - 5e^{-05} x^3 + 2.8x^2 - 75424 x + 8e^{08}$ with an R^2 of 0.92 was determined using the data from 2013. The peak potential evapotranspiration was in the range of 0.3 inches per day and the crop water use was approximately 0.23 inches per day (Fig. 2)

Orchard irrigations of DI and SDI were measured and recorded automatically with electronic flow meters and were based on lysimeter measurements and were used to calculate the water balance. Table 1 gives the components of the water balance from 2010 until December 31, 2014. Reference evapotranspiration (ET_0) was taken from the California Irrigation Management Information System (CIMIS) weather station located on KARE. The crop water use (ET_c) came from the weighing lysimeter and was adjusted for tree spacing. Precipitation came from the lysimeter rain gauge, drainage was measured in the lysimeter using a tipping bucket rain gauge located at the drain of the soil mass, and there was no runoff. We determined the crop water requirement with the high frequency irrigation up to 6 times per day. The crop water use increased from 2 inches at planting in 2010 to 36 inches in 2014. The increased water use of 9 inches in 2014 compared to 2013 is probably a result of the increased temperature and the increased tree size. The plants are reaching maturity and a size that will be maintained for yield and manageability. The crop water use in 2014 is probably representative of the long term requirement for trees that have been trained as a bush with the height limited to approximately 9 ft.

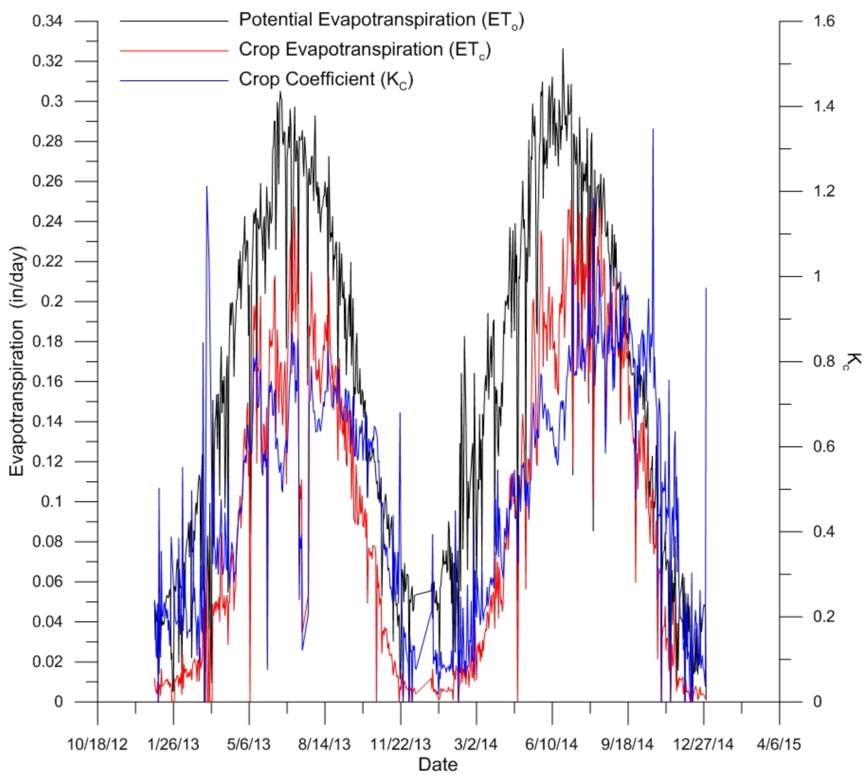

Figure 2. Daily pomegranate potential evapotranspiration (ET_o), crop evapotranspiration (ET_c) and crop coefficient (K_c) for 2013 and 2014.

Table 1. Components of the pomegranate water balance for 2010-2014.

Year	ET_o In.	Precipitation In.	DI Irrigation In.	SDI Irrigation In.	ET_c In.	Drainage In.
2010	49.7	17.3	1.0	1.0	2.1	n/a
2011	50.9	10.4	8.5	8,5	9.8	0
2012	54.6	8.97	18.6	16.8	19.7	0
2013	55.0	3.21	25.4	23.0	26.9	0
2014	57.8	8.62	33.4	30.7	35.9	0

Figure 3 shows the daily averaged soil matric potential measurements for these eight SMP sensors for 2013 and 2014. The management goal was to maintain the SMP in a range between -30 and -40 kPa. It is apparent that we were able to achieve this objective during the growing season each year. The spikes with the SMP were decreased (less negative) were a result of excess water being applied due to a malfunction of the irrigation system.

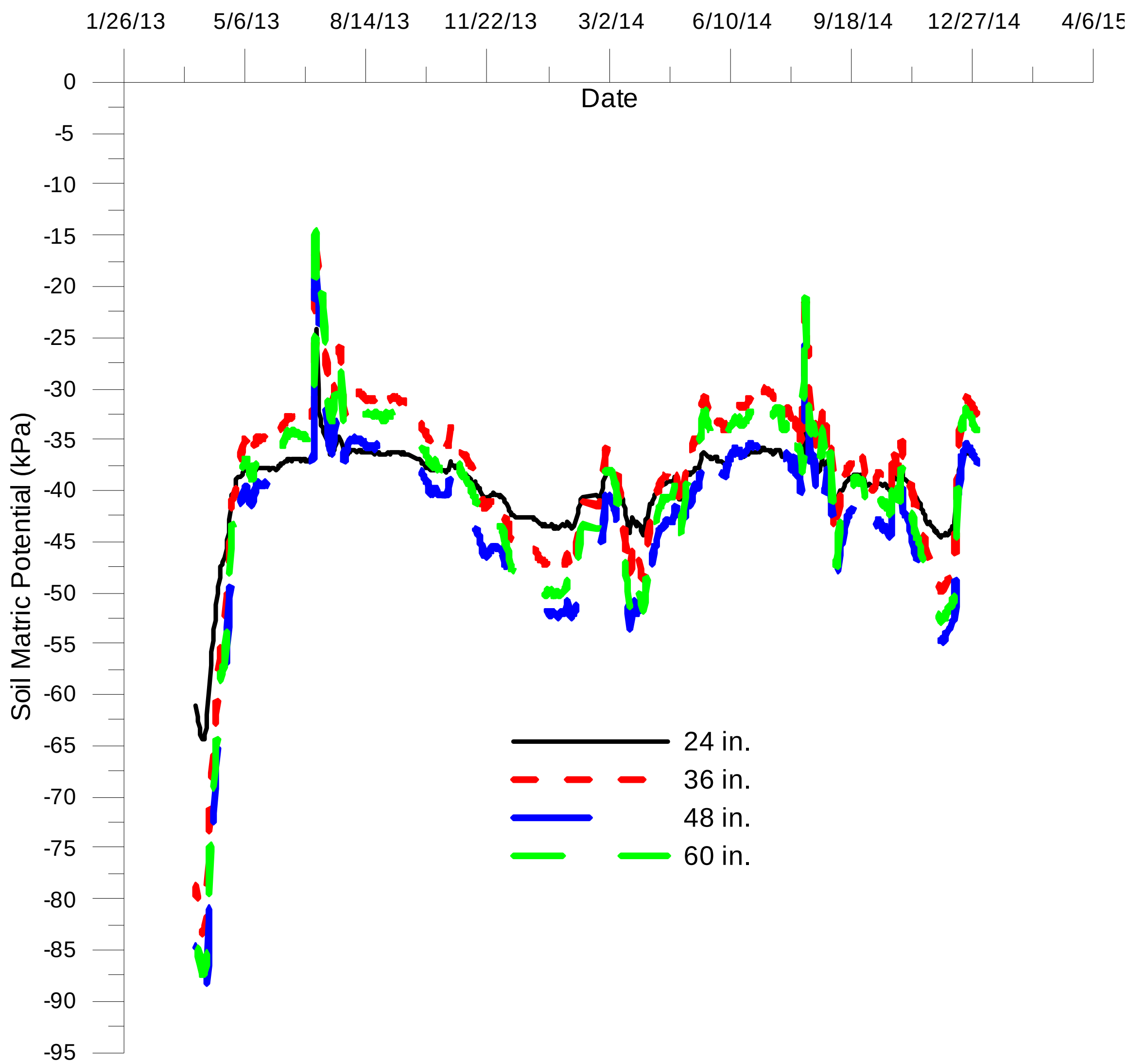

Figure 3. Daily average soil matric potential sensor measurements for 2013 and 2014.

Calculated daily averaged soil matric potential gradients (SMPG) from are shown in Fig. 4. The gradient is calculated using the Darcy's equation assuming a unit gradient. The arrows indicate the direction of flow within the root zone, with up being toward the soil surface and down towards the groundwater. HG-1 is the zone from 24 to 36 inches depth. HG-2 is the zone from 36 to 48 inches in depth and HG-3 is the zone from 48 to 60 inches of depth. The data show that there was a gradient of flow downward in the middle zone but continuously upward in the lowest zone HG-3. During most of the irrigation season the gradient and thus the flow was upward. The net result is that we control the flow within the root zone and no water and thus nitrogen was lost to the groundwater.

The three nitrogen fertility sub-treatments (50, 100, and 150% of adequate N) were based on biweekly leaf tissue analyses and applied by continuous injection of N-pHURIC (50 lb N/ac) for all treatments starting during the last week in May and additionally as AN-20 (20% N) for N-2 and N-3 treatments, starting in the second week in June in each year.

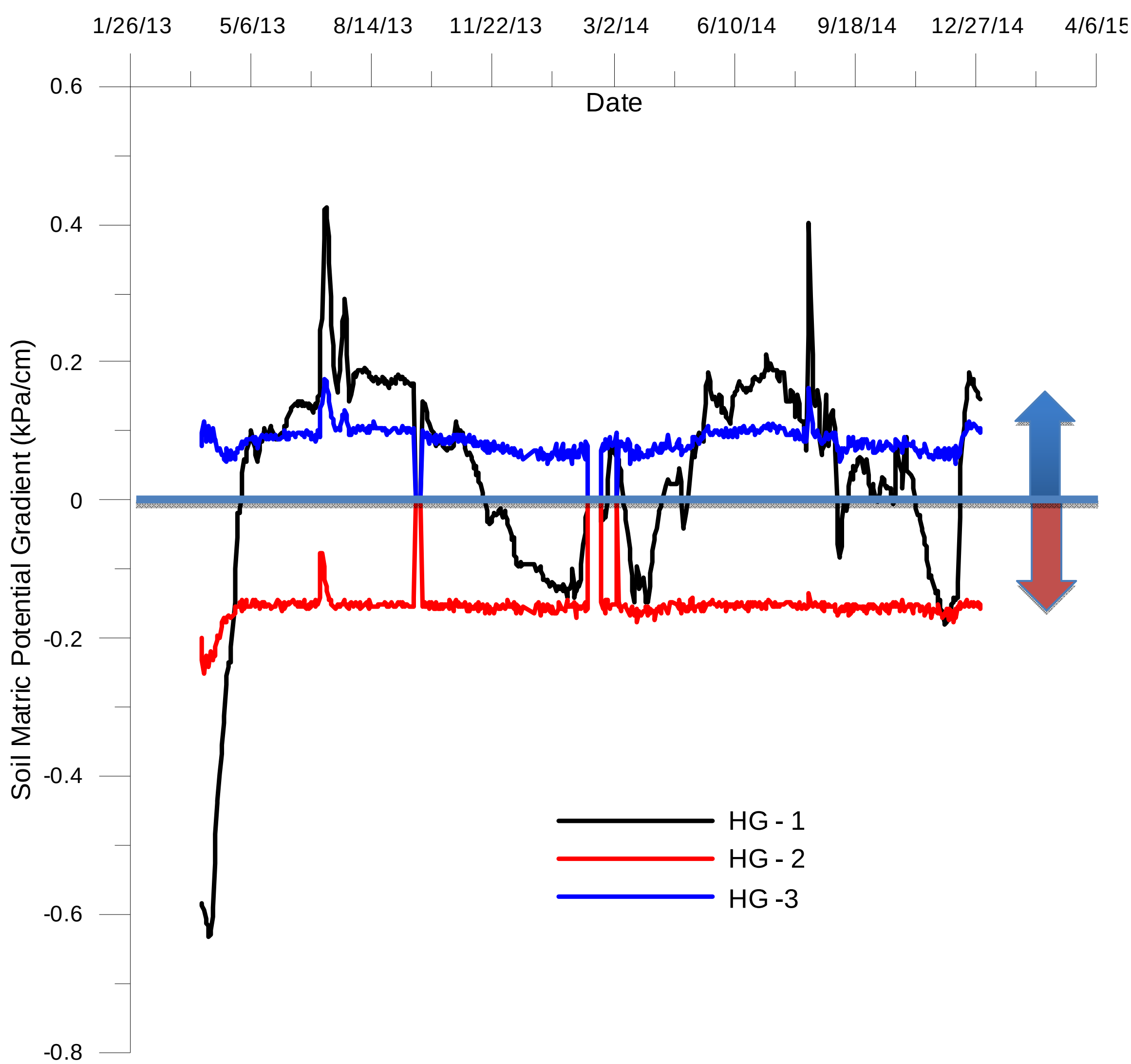

Figure 4. Soil matric potential gradients (SMPG) calculated daily for 2013 to 2014.

Phosphoric acid (H_3PO_4) is continuously injected at a rate of P=15 ppm to maintain adequate P level in the SDI treatment. Previous research has shown that phosphorus becomes deficient at soil depths greater than 8 inches. The pH of the irrigation water was automatically maintained at 6.5+/-0.5 with the N-pHURIC to avoid precipitation of phosphates that typically starts occurring when the pH is greater than 7.2.

Potassium (K_2T) was injected once weekly at a rate of K=25-35 ppm to maintain adequate K level in both SDI and DI treatments. Previous research has shown that potassium may become extremely deficient in sandy loam soil, especially as soil depth increases.

The total applied fertilizers in pounds per acre are given in table 2 for 2013 and 2014.

Year	N1 (lb/ac)	N2 (lb/ac)	N3 (lb/ac)	P (lb/ac)	K (lb/ac)
2013	62	149	249	58	65
2014	55	199	305	82	76

Yields, Water Use Efficiency (WUE) and Nitrogen Use Efficiency (NUE)

The per acre yield was estimated based on the average per tree yield as follows, ((kg/tree)x(2.205 lb/kg) X (227 tree/ac) which is equal to lb./ac. Five trees were harvested in each plot and used to calculate an average for each treatment that was used in the yield determination. The values from the individual nitrogen treatments for SDI and DI were averaged to obtain a single yield value for the drip treatments.

Table 3. Pomegranate yields in pounds per acre (lb/ac) for 2013 and 2014 by nitrogen treatments N1, N2, N3. N1 is 50% of adequate, N2 is 100% of adequate and N3 is 150% of adequate nitrogen.

	Prime (lb/ac)		Sub-Prime (lb/ac)		Green (lb/ac)		Total (lb/ac)	
	2013	2014	2013	2014	2013	2014	2013	2014
N1	6006	28245	22924	11760	581	338	29511	40343
N2	7268	30531	23085	4271	511	568	30864	35190
N3	8199	34749	22735	7967	521	634	31455	43350

Table 4. Average pomegranate yields in pounds per acre for subsurface drip irrigation (SDI) and surface drip irrigation (DI) in 2013 and 2014.

	2013		2014	
	SDI (lb./ac)	DI (lb./ac)	SDI (lb./ac)	DI (lb./ac)
Prime	7118	7188	33442	28909
Subprime	23716	22043	8761	7573
Green	651	421	389	637
Total	31485	29652	42592	37120

Table 5. Pomegranate water use efficiency (WUE) tons of fruit (T) divided by applied water in ac-in. (T/ac-in).

	2013		2014	
WUE	SDI	DI	SDI	DI
Prime	0.16	0.14	0.54	0.43
Subprime	0.52	0.43	0.14	0.11
Green	0.01	0.01	0.01	0.01
Total	0.68	0.58	0.69	0.56

Table 6. Nitrogen use efficiency (NUE) calculated as total marketable fruit (P) in pounds divided by average applied N in pounds per ac. (lb P/lb n/ac-in) by irrigation treatment in 2013 and 2014.

Year	SDI	DI
2013	201	191
2014	226	196

DISCUSSION AND CONCLUSION

Table 1 shows the components of the water balance from 2010 until December 31, 2014. There was a continued increase the water requirement as the plant developed. The water requirement in 2014 ranged from 31 to 33 inches for SDI and DI systems. This is probably representative of the mature plant requirement. With only 8.6 inches of rain in 2014, we did not record any drainage in the lysimeter even though the majority of the rain fell in December. The water use increased in 2014 compared to 2013 as a result of higher temperatures throughout the year, as well as an increase in the tree size. The trees have reached a mature stage that will be maintained as reasonable for production purposes. Except for 2010, when the drainage system was inoperative, no drainage was recorded by the lysimeter in any of the years of this experiment. This means that the rain and irrigation applied were used by the crop or were stored in the soil profile.

With the concern for transport of nitrate to the groundwater, it is essential to quantify the movement of NO_3 through and below the crop root zone. The SMP data indicate that there was good control on the irrigation system and that the soil matric potential was well controlled throughout the irrigation season. This implies that there would not have been any deep percolation losses. This is confirmed by the lack of measured drainage from the lysimeter. The hydraulic gradient calculations in figure 4 demonstrate that water was moving downward in the region of 36 to 48 inches, however in the gradient was up in the zone from 48 to 60 inches. For most of the season the SMP was maintained in the zone from 30 to 40 kPa which was the goal for the operation of the system.

The was an increase in yield over the years as the plants matured as would be expected the statistical analysis indicated that there was a response to the applied N averaged between the irrigation systems in 2014. The statistics did not indicate a response to the irrigation system type in either year, even though there were higher yields in the SDI compared to the DI system. These differences in yield were reflected in the higher WUE and NUE efficiency for the SDI system compared to the DI system, a result of higher yields and less applied water. The differences in prime weights between the years were a result of surface cracks that developed in 2013 due to a delay in harvest.

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WATER TRANSFERS STRUCTURED TO FUND ON-FARM CONSERVATION IMPROVEMENTS

Steven R. Knell, P.E.[1]

ABSTRACT

The State of California passed legislation in 2009 entitled Senate Bill (SBx) 7-7. That legislation has since been incorporated in the California Water Code as §10608.48. The purpose of the code section is three-fold;

1. To require irrigation districts to accurately measure water to each farm gate,
2. To require irrigation districts to charge volumetrically for each acre foot delivered,
3. To require irrigation districts to implement a wide array of conservation programs and measures that improve on-farm water use efficiency by its water users.

The program developed and implemented by the State is mandatory. The State imposed program provides no funding for compliance despite the fact that compliance costs will be significant. Oakdale Irrigation District (OID or District) anticipates the unfunded costs to approach $3 million dollars a year to its budget. Additionally, the unfunded cost to growers and farmers in the District will be even greater. As with most government regulations, OID and its water users are left with the task of figuring out how to pay this bill.

OID has been successful in using water transfers to willing buyers to fund its infrastructure improvements since 1999. OID's investment in infrastructure has totaled over $58 million during that period of time, most of it funded with revenues derived from water transfers. With its success in improving its operational efficiency through water transfer revenues OID began to think of ways to drive the benefits derived from water transfer to the farm level in the hopes of paying for costly on-farm improvements. From that thought OID crafted a voluntary On Farm Conservation Funding Program for the 2015 water year.

The program works as follows: irrigated lands would be idled on March 1st and not receive water again until the following March. The crop's consumptive use water that would have been applied as part of irrigation would be marketed for sale in a water transfer. The revenues of the marketed water would be returned to the landowner with the following conditions; 20% of revenues would be paid as an incentive for participation; 75% would be placed on account and available to implement an approved on-farm conservation project; and 5% of the revenue would go to OID for administration and environmental document preparations. The non-consumptive use water that was not marketed would be placed back in upstream reservoirs for uses as needed.

The following paper will outline the greater details and workings of the program.

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BACKGROUND

History of OID

In 1909 OID was organized under the California Irrigation District Act by a majority of landowners within the district in order to legally acquire and construct irrigation facilities and distribute irrigation water from the Stanislaus River (ref. Figure 1). In 1910 OID and the neighboring South San Joaquin Irrigation District (SSJID) purchased Stanislaus River water rights and some existing conveyance facilities from previous water companies. Both districts continued to expand their operations over the ensuing decades.

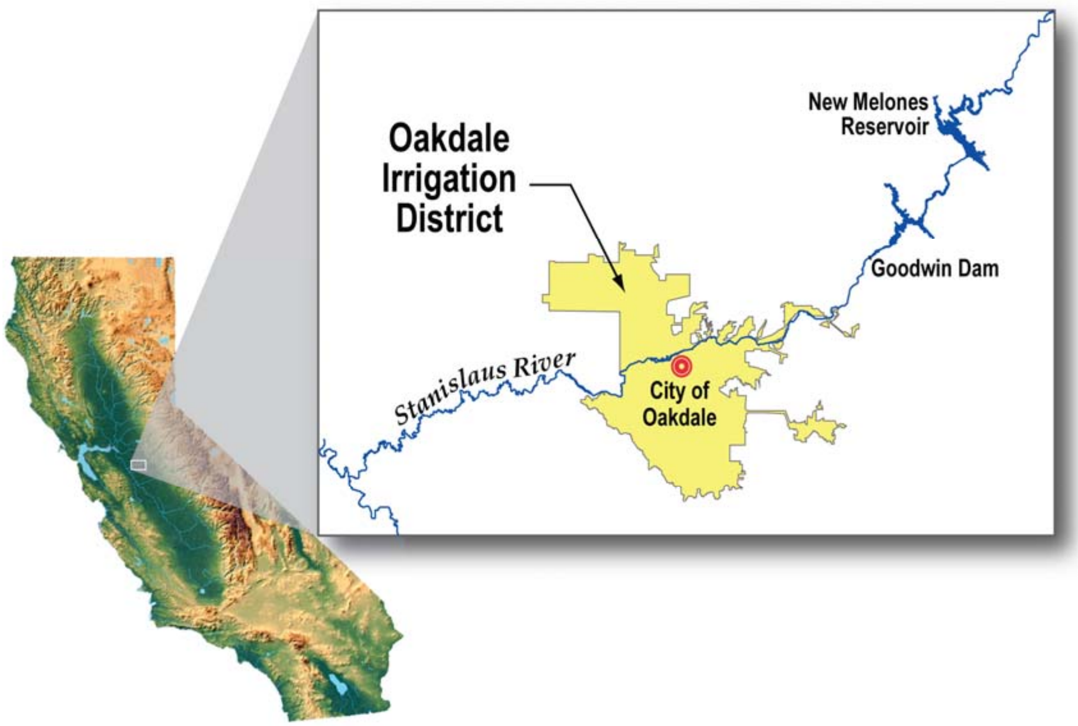

Figure 1. Location of Oakdale Irrigation District

Since their creation, OID and SSJID have constructed dams and reservoirs to regulate surface water storage and deliveries. Most dams were constructed in the 1910s and 1920s, including Goodwin Dam (1913), Rodden Dam (1915), and Melones Dam (1926), which provided 112,500 acre-feet (ac-ft) of shared capacity. To provide supplemental water storage for OID and the SSJID, the Tri-Dam Project was created in the 1940s. Sites were approved in 1948 for Donnells Dam and Beardsley Dam on the Middle Fork of the Stanislaus River, and for Tulloch Dam above Goodwin on the main stem of the Stanislaus River. The two districts entered a joint agreement to carry out the proposed project and now jointly own and operate the three storage reservoirs for a combined storage capacity of 230,400 ac-ft.

In the early 1970s the Bureau of Reclamation (Reclamation or Bureau) replaced the Melones Dam with the larger New Melones Dam and Reservoir. The districts have an operations agreement with Reclamation to utilize the federally owned New Melones Reservoir for the delivery of its senior water rights.

These historical capital investment has led to a stable, plentiful water supply for the district. Over the last 50 years, the district has focused its financial resources principally on paying off these capital investments; as a result, the district has invested little in replacement, modernization, automation or rehabilitation of its existing system over the years. That focus changed in 2004.

The District Today

Currently, the district maintains over 330 miles of laterals, pipelines, and tunnels, 29 production wells, and 43 reclamation pumps to serve local customers. Refer to Figure 2 for more details about OID.

OAKDALE IRRIGATION DISTRICT FACTS

Year OID was organized: 1909

Total district acreage: 72,500

Total irrigated acres: 62,300

Annual diversion right: 300,000 acre feet

Diversion point: Goodwin Dam

Maximum diversion rate from Goodwin Dam: 910 cfs

Total distance of water delivery system: 330 miles of canals (open, lined, and buried pipelines)

Number of agricultural wells: 24

Number of agricultural water accounts: 2,900

Percent of OID agricultural customers who farm parcels of 10 acres or less: 60 percent, constituting 12 percent of OID land

Percent of OID agricultural customers who farm parcels of 40 acres or more: 4 percent, constituting 60 percent of OID land

The combined storage capacity for Tulloch, Beardsley, and Donnells Reservoirs: 230,400 ac-ft

Combined power generation of hydro-electric facilities: 81,000 kilowatts

Figure 2. OID Facts

In general, the district's facilities, system operations, political organization, and administration have not changed significantly over the last several decades. Nearly all water supply canals were constructed more than 100 years ago. In recent years however, the district's customers, land use, and financial resources have developed in a direction that is influencing the way OID provides services and conducts business.

Oakdale Irrigation District (OID) provides pre-1914 water rights to over 62,000 acres of irrigated farmland located within the northern San Joaquin Valley of California. Initiated in November 2004 and completed in June 2007, OID developed a Water Resources Plan (WRP) as a strategic roadmap for addressing its future infrastructure and modernization needs. Today the district is moving forward with the implementation of a $170 million capital improvement program to meet the multifaceted needs of the district. Those needs as outlined in the WRP include the protection of the District's water rights; an increase in agricultural water supply reliability during droughts; protection for the local area's surface and groundwater supplies; along with a roadmap to modernize and rebuild a century old system to meet the needs of its changing customer base. Regional water transfers have been used as the basic funding mechanism to make this all happen.

OVERVIEW OF WATER TRANSFERS

History of Water Transfers at OID

OID began transferring water in 1999 through two separate contracts. One to Stockton East Water District (SEWD) for their treatment and delivery to the City of Stockton and one contract to the United States Department of Interior, Bureau of Reclamation. A portion of water under the Bureau contract was for use in a fish study called VAMP (Vernalis Adaptive Management Plan) and the second portion of that contract was for ancillary water to meet dissolved oxygen and salinity objectives at Vernalis as required under the Bureau's operating permit from the State of California for New Melones Dam and also for miscellaneous fish flow needs.

These two contracts at inception in 1999 had 10 year terms with renewal clauses that effectuated their ending dates in the fall of 2010 for SEWD and in 2011 for the Bureau. In 2009 OID made a water transfer to the San Luis & Delta Mendota Water Authority (SLDMWA) and in 2013 OID made a water transfer to the SLDMWA and the California Department of Water Resources (State Water Contractors).

Over the course of these transfer years OID moved 575,000 acre feet of water and generated a revenue stream totaling $49.1 million dollars. On average the aggregate price of water marketed was just over $85 per acre foot on these contracts. The cost of water to purchasers ranged from $60 to $250 dollars depending on circumstances, hydrology and need.

Water Markets Available to OID

There are three types of water markets OID has been involved with over the years. Each market has a different ability to pay and comes with a different set of politics.

<u>High End Metropolitan Areas:</u> These markets come with a high capacity to pay but in-district politics for completing such transactions can be difficult. Water kept locally serving local needs is a common public statement on these types of contracts and is not without merit. However, the benefit in marketing to high-end metropolitan areas is the potential for high returns with the least amount of water being transferred. Despite the desire to keep water local, water agency budgets still have to be met and water transfer revenues are a significant part of the OID's budget. With that perspective though,

balancing the financial needs of the district and the needs of the local community is the driver of discussions at the local level.

Local / Regional / Municipal Areas: These markets are only now willing to consider paying the true value of water. For many years, the local and regional areas have relied on a seemingly abundant availability of both surface and groundwater supplies that has now become less than reliable in the San Joaquin Valley. With the implementation of the State's Groundwater Management Sustainability Act of 2014, Senate Bill x7-7, changes to the arsenic rule, rising nitrate contamination, salt water intrusion and groundwater degradation from years of overdraft, etc. cities in the local and regional markets are only now beginning to see reliability constraints in their future water supplies.

Agricultural Market Areas: This local agricultural market's capacity to pay is simply defined and premised on what makes business sense. This market compares the cost of surface water with the cost of pumping groundwater. In the area east of Oakdale, where agricultural is expanding solely on the reliance of groundwater, that current cost is approximately $80-$100 per acre foot, depending on depth to groundwater. While the market is easy to define, the cost conscientious farmers in the area, despite long term sustainability questions, still have little interest in paying more for surface water if the cost to pump groundwater is less.

Markets on the westside of the San Joaquin Valley, which rely on Central Valley Project (CVP) water or groundwater if insufficient CVP water available, have a different perspective. Groundwater on the westside can be as deep as 200-400 feet or deeper and is extremely costly to pump compared to CVP water if and when it's available. This market and the capacity to seek transfer water to reduce groundwater pumping has grown in recent years.

Environmental Market Areas: Purchase of water to meet environmental needs was a premise of the original Bureau contract mentioned previously. In two of the latest OID water transactions to the SLDMWA/DWR, water was released on a fish friendly schedule as part of a pulse flow. While not a direct payer for the benefit, the ability be have both water transfers and environmental benefits is a doable option that needs consideration.

The Water Market End Game

The end game in water transfers is always to provide the maximum protection to the district's water rights and to insure reliable, adequate water deliveries to the farming community within the service area of the district before any water is marketed. Meeting that goal may best be met by having equal participation of transferred water in each market area. Politically, this strategy may provide the broadest base of support to a legal challenge to one's water right in the future.

Benefit of Water Transfers - Improving Water Use Efficiency

As outlined in OID's Water Resources Plan, revenues derived from water transfers were directed at making infrastructure and modernization changes in OID's water delivery system. Those changes significantly improved OID's capacity to deliver water more efficiently and with better control, thereby enhancing customer service.

As an indicator of the changes OID has been able to achieve over the last 10-year period though the use of water transfer revenues in funding infrastructure improvements can best be represented in the two figures below. Figure 3 represents the water use baseline established in 2001 as part of OID's Agricultural Water Management Plan. This "Plan" was submitted to the Department of Water Resources in compliance with the Agricultural Water Suppliers Efficient Water Management Practices Act of 1990 (AB3616).

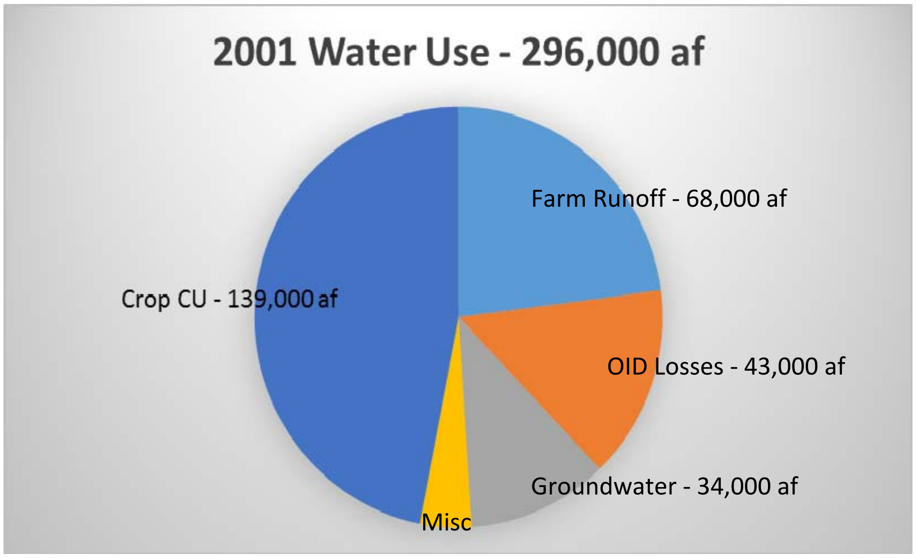

Figure 3. Data from OID's 2001 Ag Water Management Plan

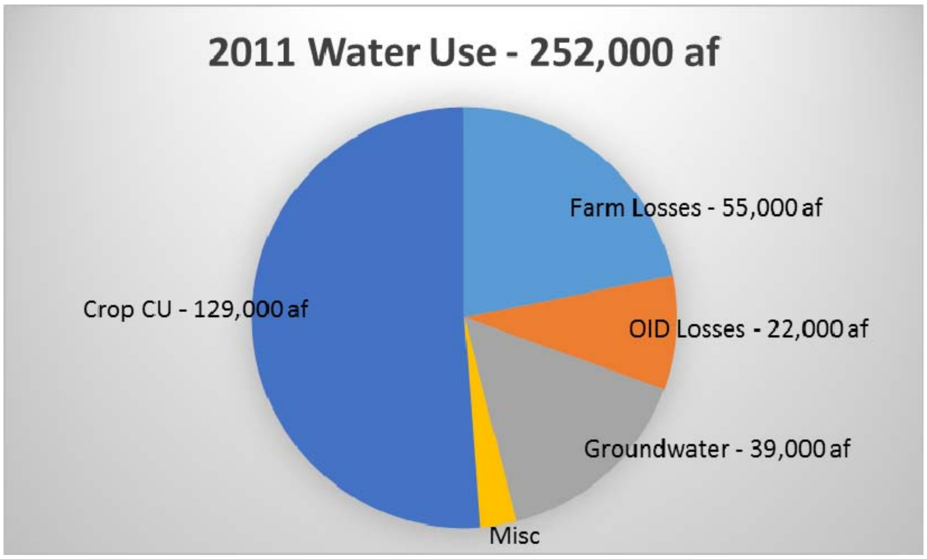

Figure 4. Data from OID's 2011 Ag Water Management Plan

Figure 4 represents the water use baseline in OID's 10-year update to that same Plan. This Plan was submitted in compliance with the requirements of the Water Conservation Act of 2009 (SBx7-7)

To clarify the terms used in Figures 3 and 4 above;

- Crop CU: The amount of water consumed solely by the crop

- Farm Runoff: The amount of water that leaves the OID service area in the form of tailwater or runoff.

- OID Losses: The amount of operational or carriage water that "spills" out the ends of laterals and canals within the OID conveyance system.

- Groundwater: The amount of water that is "net" to the aquifer coming from deep percolation losses on-farm, seepage from OID laterals and drains, etc.

Over the span of this 10 year period, OID has been able to reduce its annual water demand by 44,000 acre feet. That reduced demand is quantified as follows;

- The change in Crop CU is attributable to land use changes in the conversion of pastureland to less water intensive crops like almonds and walnuts.

- The change in OID Losses is a direct result of operational improvements through modernization and automation of OID's main canal delivery system and lateral head-gates and the installation of two regulating reservoirs.

- The change in Farm Runoff is a result of two factors. One being the conversion of pastureland to trees and the installation of drip systems in much of these orchards, reducing or eliminating runoff. The other factor is the enhanced control of water by OID by the modernization of its delivery systems in providing improved farm deliveries at the farm gate.

  It is difficult to achieve high water use efficiency on-farm if the water deliveries from the irrigation district are inconsistent and lack flexibility in the frequency, rate and delivery of water to the farm. The more efficiently an irrigation district can deliver water to the farm the more efficient the farm can be in the application of that water.

- The change in water going to Groundwater is an interesting note. With the addition of automated canal and lateral structures system wide, OID is not having to drain and fill laterals as often between irrigation events. That operational change leaves water ponded in the system more often and hence, we believe, allows more seepage is occur to the aquifer. This is not necessarily a bad thing.

BRINGING WATER TRANSFER BENEFITS TO THE FARM GATE

Background on Needs for a Program

The State of California passed legislation in 2009 entitled Senate Bill (SBx) 7-7. That legislation has since been incorporated in the California Water Code as §10608.48. The purpose of the code section is three-fold;

1. To require irrigation districts to accurately measure water to each farm gate,
2. To require irrigation districts to charge volumetrically for each acre foot delivered,
3. To require irrigation districts to implement a wide array of conservation programs and measures that improve on-farm water use efficiency by its water users.

This State imposed program is mandatory and provides no State funding for compliance hence putting the cost burden upon agricultural districts and their constituents. These unfunded costs to OID are estimated to add $3 million dollars to the OID budget per year. Depending on conservation practices installed, the cost to the farm gate could be significant more.

In an effort to meet the financial challenges brought on by SBx7-7, OID recently approved a water rate increase to cover some of the cost of implementing the law. That rate required a doubling of the past rate and the ire of many agricultural water users.

Many of OID farm parcels are ill-equipped to pay for the financial burden these changes bring to their farming operations. OID is a mix of both high value and low value crops. While some of the high value crops can afford to do more, it leaves few options for those farming low value crops to come up the revenues to make conservation improvements.

With the successes OID experienced using water transfer revenues to fund its system improvements the idea of bringing that same benefit to the farm to improve on-farm irrigation systems emerged. With that as the goal, OID crafted an On-Farm Conservation Funding Program. The framework of that program follows.

PROPOSED PROGRAM (DRAFT)
ON-FARM CONSERVATION FUNDING AND SBX7-7 COMPLIANCE PROGRAM

Eligibility Criteria

- Participation is VOLUNTARY
- Open to all parcel sizes.
- Enrollment acreage limited to 2,500 acres per year.
- Program enrollment period from March 1, 2015 to September 30, 2015.
- Participant lands must have irrigated 3 out of the last 4 years.
- Participant lands will be limited to the following water allocations by crop for funding calculation purposes:

    - 4.0 acre feet/acre for pastureland
    - 3.5 acre feet/acre for rice land
    - 2.5 acre feet/acre for corn/oats
    - Crop allocations not listed shall be determined by the Consumptive Use of the crop between the months of March 1 to October 1
- Participant lands on private pipelines must have ability for positive shut-off to field.
- Ease of verification.
- Participant lands shall not employ <u>any</u> groundwater, surface water or drain water substitution during enrollment in the program.

<u>Approved Water Conservation Practices</u>

- Pipelines that replace open ditches. Includes all associated parts.
- Pipelines that replace old pipelines. Includes all associated parts.
- Laser land leveling with sub-soiling and reseeding.
- Tail-water Recovery or Pump-back systems. Includes pump and electrical.
- Land conversions from high water use crops to lower water use crops.
- Conversion to higher efficiency irrigation systems.
- 50% of Conservation Practice monies to small parcel may be applied to actual costs of lowering, replacement or deepening of domestic wells.

<u>Terms</u>

- This program is a 1-year program.
- Water made available by participant lands would be marketed at $400 per acre.
- Funding levels for conservation practices will be determined by multiplying the market rate of water per times the crop allocation provided earlier.
- Funding from program will be allowed to spent in the following areas;
    - 20% cash incentive to landowner/participant
    - 75% installation of approved conservation practices
    - 5% OID administration costs
- All participant lands must have a measurable gate or meter at their point of delivery, compliant with SBx7-7 requirements, or that will be one of your conservation projects under the program.
- Contractors/landowners working within OID easements must be pre-approved by OID.
    - Participant land must be compliant with OID easement criteria at the end of the project.
- NRCS standards and specifications will apply to all work.
- Participant land must be registered with the Irrigated Lands Coalition.
- Tenants are responsible for obtaining all landowner approvals for program participation.
- Any irrigation water, regardless of source, on the participant property during the Program Year of enrollment will result in lands ineligibility for any payment.

- OID to pay on submitted invoices after field verification that the work has been completed and compliant with NRCS standards.
- OID will make water available the entire month of October to assist in establishment of re-vegetated fields.

Program Interest

OID began receiving Solicitation of Interest Forms for the program at its first meeting in December 2014 and stopped solicitations in mid-January 2015. At the end of that period, OID had 143 parcels covering 3,250 acres of lands that had submitted statements of interest in the program. Of those submitted 50 parcels were 10 acres or less, 54 parcels were 10-40 acres in size and 20 parcels were over 40 acres.

On a crop mix basis, 1,760 acres were pasturelands, 690 acres were corn/oat lands and 800 acres were a mix use of lands.

Program Success

OID believes the response to the program is an overwhelming affirmation that such programs can bring value to the participants. While in the short term, the program affords the landowner sufficient capital to improve its irrigation system, it's the long term benefits that will provide the most value.

Program Benefits

Modernized irrigation systems provide a level of water control that will reduce wasteful runoff and excessive deep percolation losses. Reduced runoff means less water running off the fields carrying less contaminants. Improved water control enhances irrigation uniformity leading to greater production values to the farmer. Less water wasted or lost puts water back in storage for drought resiliency benefitting all constituents of an irrigation district.

An often omitted value of such a program is the ability to bank all the non-consumptive use water not delivered to the field. For a number of management reasons, this is substantial. Eliminating water losses from delivery inefficiencies for a field that sits idle for a year, and making that water available to meet a broader range of constituent demands is a significant management tool. Whether that purpose if for meeting water demands in a drought or for banking additional supplies for subsequent years, as carryover storage, are all value added benefits of this program.