Attachment 1
Measurement Objectives and Components

This section provides background on the objectives and components of measurement for the definition of appropriate agricultural water use measurement. The first part of this section covers the four objectives of measurement. The second section covers the generic location of where measurements are taken (surface water diversion points, farm-gate deliveries etc) and what type of measurement is made for example the procedure for determining net groundwater use is presented.

Measurement of agricultural water use meets many local needs. Measurement data can help local water districts distribute water to farms, make operational decisions and improvements, and charge for water according to the amount used. In recent years, as California's water resources have become increasingly scarce, diverse stakeholder groups also have recognized the importance of measurement to state and federal agencies trying to manage a much-in-demand resource. The focus of this analysis is on these state and federal needs, which fall into four broad categories: water planning, water availability determination, water transfers and water use efficiency.

Water planning and availability determination represent two ongoing tasks that state and federal agencies have been involved in for decades. Water transfers and use efficiency are more recent efforts that are gaining momentum because of increased demands for the finite water resources.

Below is a more detailed look at each of these four primary objectives.

Planning

State and Federal agencies use water measurement to plan for changes in supply and demand of water resources. Water measurement information is used to make changes in the physical and managerial aspects of the storage and conveyance of water. Specifically, water measurement information is used by the State and Federal government to:

- Forecast and verify water supply;
- Meet regulatory requirements for water quality and quantity;
- Conduct feasibility analysis for system improvements;
- Determine timing of water availability for customers;
- Develop budget information for water supply infrastructure;
- Establish water use policies;
- Help monitor conditions of water resources in particular regions to determine whether they should be given special designations and provided with special funding opportunities or regulatory requirements;

- Help monitor status of resources that have already been identified as facing special problems and subjected to special requirements;
- Help inform scientific research work relating to potential improvements in water resource management at the state-, district-, intermediate-, and end user level;
- Facilitate evaluation of the impacts of land use and development activities on water-related resources;
- Facilitate evaluation of availability of water for proposed future land uses;
- Prepare and coordinate contingency plans for different water-year types; and,
- Uphold doctrine of public trust.

The locations of measurement devices enable the monitoring of inflow and outflow to various facilities and river courses as well as various internal sites that provide adequate coverage of the distribution infrastructure. In addition to flow and volume measurements, water quality measurements are often required. Due to the extensive movement of water throughout the state, planning is required for local, regional and statewide needs.

Water Availability Determination

State and federal water suppliers have a fundamental requirement to fulfill water contract obligations and ensure appropriate use of water. In addition the State has a responsibility to protect and enforce water rights. Measurement information can assist the State to:

- Allocate water in a manner that ensures irrigation water is provided according to water rights or contract status;
- Provide a verifiable basis for administrative and judicial decisions regarding new permit applications and amendments to existing permits, sales of existing water rights, water transfers, adjudications, conjunctive use of surface and groundwater;
- Help coordinate water release schedules for stored water;
- Help determine the availability of water for further appropriation in order to evaluate whether new water right permits may be issued;
- Maintain and administer a system of water rights;
- Comply with legislative mandates; and,
- Comply with interstate compacts and international treaties.

This purpose necessitates gathering data about state, federal and local water supplies, as well as local water requirements. These measurements must ultimately provide for a general accounting of the state's water resources, uses and destinations. These issues vary by region throughout the state.

Transfers

Water measurement information is critical to water transfers. Specifically, water measurement information can be used to:

- Help determine the potential for water transfer programs at local and regional scales;
- Show past consumptive use in order to transfer that amount only; and,
- Verify water transfer programs.

This information is required because the open and inter-connected nature of the water distribution system in California necessitates the verification of any assumption that water transfers are on a one-for-one basis. Complete and accurate information on historic water use - and the hydrologic implications of water transfers – are required to ensure that the proposed transfers are valid and that the transfer does not have third party impacts. Water transfers affect the majority of the agricultural regions throughout the state.

Water Use Efficiency

In addition to the general water measurement objectives of planning, water availability determination and transfers, there are specific regional or statewide objectives that in some instances require a finer resolution on the array of measurement locations. To date, the Water Use Efficiency element of the CALFED Bay Delta Program has identified flow and timing, water quality and water quantity objectives related to irrigated agricultural that require additional measurement points to monitor and verify. Because the Water Use Efficiency element of CALFED is objective-based, no pre-determined efficiency value is sought.

Flow and timing objectives are based primarily on meeting environmental needs; they are not concerned with generating new or wet water but rather altering the timing of diversions or return flows. Additional measurement points are expected to provide a foundation to manage and verify the flow path changes. Water quality objectives are based on reducing pesticides, changing water temperature for sensitive species and reducing native constituents such as selenium, boron, salt and total organic carbon. Additional water quality measurement points are expected to provide a foundation to manage and verify changes in loading rates and total mass of constituents added to the water. Water quantity objectives are related to increasing the supply of water available for beneficial uses and are met through reducing flows to salt sinks or reducing non-beneficial evaporation or transpiration flows. As with flow and timing, additional measurement points are expected to provide a foundation to manage and verify the flow path changes for water supply.

The regional objectives (Table 1.1) are presented as "first approximations;" the extent of the number, type or location of measurement devices is not presently known. For each of the listed regions the objectives are assumed to have a linkage to irrigated agriculture. In areas that affect flow to the Delta, CALFED's Quantifiable Objectives are used to represent regionally based needs that are generally external to water suppliers. For all other areas, professional judgment is used to estimate the category of need. Below is a brief summary of regional Quantifiable Objectives (Figure 1.2).

Sacramento Valley: This area is bounded by the American River and Yolo County in the south and Lake Shasta in the north. The primary objectives in this area are flow and timing and temperature needs on the American, Sacramento, Yuba and Feather Rivers and their tributaries. In addition, there are several water quality needs that cover pesticides and salinity.

Delta: This area is bounded by the Cosumnes, Calavaras and Mokelumne River watersheds and the Delta. This area has specific objectives in all categories.

Eastside San Joaquin Valley: This area is bounded by the Tuolumne, Merced and San Joaquin River watersheds. The primary CALFED objectives are related to flow and timing, and temperature needs on the primary rivers. In addition, there are several water quality concerns in all of the major rivers.

Westside San Joaquin Valley: This area is bounded by the San Joaquin River on the east, the coast range on the west, Fresno County to the south and Stanislaus County to the north. The main objectives in the region are for water quality and to reduce flows to salt sinks; there are no flow and timing objectives.

Southern San Joaquin Valley: This area is bounded by the southern divide of the Merced River watershed, the coast range on the east down to the base of the Tehachapi Mountains. The objectives in the region are for water quality and to reduce flows to salt sinks; there are no flow and timing objectives.

Other California: This covers agricultural regions that are not included in the above regions. The primary locations are the Imperial and Coachella valleys that have the majority of the irrigated acreage and are hydraulically linked to the Delta. Other agricultural areas include San Diego, the Central Coast through Salinas and the Napa Valley. These coastal regions have significant irrigated acreage but have limited involvement with the Delta. Within this area there are water quality and water quantity Water Use Efficiency objectives.

Table 1.1. CALFED listing of Quantifiable Objectives.

Targeted Benefits will be achieved by altering flow paths of irrigated agriculture.

Region		Sub-Region	Abbreviated Categories of Targeted Benefits											
				Quality							Quantity			
			Flow / Timing	Nutrients	Group A Pesticides	Pesticides	Salinity	Native Constituents	Temperatures	Sediments	Long-Term Diversion Fleüibility	Nonproductive Evaporation	Short-Term Diversion Fleüibility	Flows to Salt Sinks
Sacramento Valley	1	Redding Basin	✔								✔	✔		
Sacramento Valley	2	Sacramento Valley, Chico Landing to Red Bluff	✔			✔			✔		✔	✔		
Sacramento Valley	3	Sacramento Valley, Colusa Basin	✔		✔	✔	✔				✔	✔		
Sacramento Valley	4	Mid-Sacramento Valley, Chico Landing to Knights Landing	✔			✔	✔				✔	✔		
Sacramento Valley	5	Lower Feather River and Yuba River	✔		✔	✔	✔		✔		✔	✔		
Sacramento Valley	6	Sacramento Valley Floor, Cache Creek, Putah Creek, and Yolo Bypass	✔			✔					✔	✔		
Sacramento Valley	7	Lower Sacramento River below Verona	✔			✔	✔		✔		✔	✔		
Delta & Tributary	8	Valley Floor east of Delta	✔						✔		✔	✔		
Delta & Tributary	9	Sacramento - San Joaquin Delta	✔	✔	✔	✔	✔	✔	✔		✔	✔	✔	✔
West Side SJ Valley	10	Valley Floor west of San Joaquin River	✔		✔	✔	✔	✔		✔	✔	✔		✔
East Side SJ Valley	11	Eastern San Joaquin Valley above Tuolomne River	✔	✔	✔	✔	✔		✔		✔	✔		
East Side SJ Valley	12	Eastern Valley Floor between Merced and Tuolomne Rivers	✔		✔	✔	✔		✔		✔	✔		
East Side SJ Valley	13	Eastern Valley Floor between San Joaquin and Merced Rivers	✔		✔	✔	✔		✔		✔	✔		
West Side SJ Valley	14	Westlands Area								✔	✔	✔		✔
Southern SJ Valley	15	Mid-Valley Area									✔	✔		✔
Southern SJ Valley	16	Fresno Area	✔		✔	✔	✔		✔		✔	✔		
Southern SJ Valley	17	Kings River Area									✔	✔		✔
Southern SJ Valley	18	Kaweah and Tule River Area									✔	✔		✔
Southern SJ Valley	19	Western Kern County									✔	✔		✔
Southern SJ Valley	20	Eastern Kern County									✔	✔		
Southern SJ Valley	21	Kern River Area									✔	✔		✔

✔ represents 1 or more TB

Figure 1.1. Geographic regions used for analysis.

Measurement Components

There are three critical aspects of measurement: (1) the generic location (i.e., surface water diversion and farm gate deliveries) of where the measurement is made; (2) the intensity of the measurement (in other words, how the information is derived); and, (3) the fate of the data associated with a measurement (how the data is used). These three aspects – summarized below – provide the technical foundation for much of the analysis presented elsewhere in these materials.

Measurement Location

In developing the technical analysis, only the major flow paths are discussed. The Technical Team acknowledges that there are additional flow paths, including deep percolation, canal seepage and open water body surface evaporation. However, the analysis suggests it is not presently technically possible to measure these other flow paths on a comprehensive basis.

Below is a summary of the seven primary measurement locations serving as the focus for this analysis:

- **Surface water diversions:** These represent surface water supplies that are taken by water suppliers or individual growers from rivers, lakes, reservoirs or large multi-district canals.
- **Groundwater use:** This represents the net use of groundwater by individual growers or water suppliers.
- **Crop consumption:** This represents water flowing to the atmosphere through crop transpiration and evaporation.
- **Return flow:** This represents water returned to public water bodies (lakes, streams, regional canals) downstream of irrigation diversions. For the purpose of this analysis, return flow points were defined as water that originates from district spills, surface runoff or drainage.
- **Water quality:** Water quality represents a dimension of measurement that is used to establish the useful capacity or impairment of water.
- **Farm-gate turnouts:** This represents the delivery of surface water to individual customers.
- **Stream Gauging:** Stream or drainage way measurements sites that provide flow and water quality information.

Measurement Intensity

Measurement intensity describes how the estimate or measurement procedure quantifies the volume or quality of water moving past a measurement point. The current use of a particular level of measurement intensity is assumed to be driven by local need or to meet a regulatory or permitting requirement. Table X.1 presents a summary of the following intensity levels that are considered for all measurement components. For each location, the definition of measurement method or device is presented at three levels - Basic, High and Highest Technically Practical. Although the terminology of the level of measurement is constant, the definition is tailored to be appropriate for each location.

Basic: Estimate flow rate and track delivery duration. The quantity of water moving past the measurement point is the product of the flow rate and delivery duration. The accuracy associated with this level is dependent on the flow conditions. Generally, the more stable the flow conditions the more accurate the quantification. Different methods or procedures are used for groundwater use, crop consumption and water quality. The corresponding scenario for each of the seven measurement locations described above is as follows:

- **Surface water diversions:** Estimate flow rates for water delivery structures once per year. Track delivery duration and use flow estimates to calculate volume delivered.
- **Groundwater use:** Calculated as the closure factor after estimating crop water consumption, surface water deliveries and surface return flows. (A full description of this procedure is presented at the end of this section.)
- **Crop consumption:** Based on an infrequent (every five years) inventory of crop acreage, existing crop coefficients and ground based CIMIS stations.
- **Return flow:** Estimate flow rates for water delivery structures once per year. Track delivery duration and use flow estimates to calculate volume delivered.
- **Water quality:** Ad-hoc samples taken without a scheduled sampling interval.
- **Farm-gate turnouts:** Estimate flow rates for water delivery structures once per year. Track delivery duration and use flow estimates to calculate volume delivered.
- **Stream gauge:** Continuous water level measurement of a cross section that is surveyed annually.

High: For structures, measure flow through rated gates, pipes or structures three times per day and track delivery duration. The quantity of water moving past the measurement point is the product of the flow rate and delivery duration. The accuracy of this intensity is better than the estimate level but is also dependent on the stability of the flow conditions. Different methods or procedures are used for groundwater use, crop consumption and water quality. The corresponding scenario for each of the seven measurement locations is as follows:

- **Surface water diversions:** Inventory and rate structures. Measure flow rates, on average, three times per day.
- **Groundwater use:** Based on a continuous regional characterization of groundwater volume using two methods: a detailed hydrologic balance and water table method. (A full description of this procedure is presented at the end of this section.)
- **Crop consumption:** Direct measurement of evapotranspiration using remote sensing based on a 32-day time step (frequency of LANDSAT 7 flyover is 16 days) with a 30m resolution during the growing season.

- **Return flow:** Inventory and rate structures. Measure flow rates, on average, three times per structure use.

Table X. Summary of generic measurement locations, improvement levels and associated definitions.

Generic Measurement Location	1/Potential Measurement Improvement	2/Definition of Potential Measurement Procedure
Surface Water Diversion	Basic	Estimate flow rates for water delivery structures once per year. Track delivery duration and use flow estimates to calculate volume delivered.
	High	Inventory and rate structures. Measure flow rates, on average, three times daily per structure use.
	Highest Technically Practical	Inventory and rate structures. Install flow totaling devices, data loggers, and telemetry where needed.
Ground water Use	Basic	Closure factor after estimating crop water consumption, surface water deliveries and surface return flows.
	High	Continuous regional characterization of groundwater volume using two methods: detailed sub-basin level hydrologic balance and water table method.
	Highest Technically Practical	Totalizing flow meters or pump testing coupled with an estimate of the surface runoff or deep percolation of the pumped water. Install flow totaling devices, data loggers, and telemetry where needed.
Crop Consumption	Basic	Based on an rolling (every five years) inventory of crop acreage, CIMIS and existing crop coefficients.
	High	Remote sensing (LANDSAT 7) based on a 32 day time step with a 30m resolution during the growing season.
	Highest Technically Practical	Remote sensing based on a 16 day (highest frequency of LANDSAT 7 flyover) time step during the irrigation season with a 30 m resolution.
Return flow	Basic	Estimate flow rates for water delivery structures once per year. Track delivery duration and use flow estimates to calculate volume delivered.
	High	Inventory and rate structures. Measure flow rates, on average, three times per structure use.
	Highest Technically Practical	Inventory and rate structures. Install flow totaling devices, data loggers, and telemetry where needed.
Water Quality (Surface and Ground water)	Basic	Ad-hoc samples taken without a scheduled sampling interval.
	High	Frequency of sampling would be prescribed by protocol and constituent of concern.
	Highest Technically Practical	Frequency of sampling would be prescribed by protocol and constituent of concern. Applies to constituents that can be measured on a continuous basis (dissolved oxygen, conductivity, pH, temperature).
Stream Guaging	Basic	Continuous water level measurement of a cross section that is surveyed annually.
	High	Continuous water level measurement, of a cross section that is surveyed monthly.
	Highest Technically Practical	Continuous water level measurement, of a rated control section consistent with the USGS criteria.
Farm-gate deliveries	Basic	Estimate flow rates for turnout structures once per year. Track delivery duration and use flow estimates to calculate volume delivered.
	High	Inventory and rate structures. Measure flow rates, on average, three times daily per structure use
	Highest Technically Practical	Inventory and rate turnout structures. Install flow totaling devices, data loggers, and telemetry where needed.

1/all levels of Potential Measurement Improvement include data: collection; quality control and assurance; analysis; reporting and archiving

2/comprehensive definitions for each level are provided in other sections of the document

3/this refers to structure capability not implementation of sturcture use, further details provided elsewhere in document.

- **Water quality:** Frequency of sampling prescribed by protocol and constituent of concern.
- **Farm-gate turnouts:** Inventory and rate structures. Measure flow rates, on average, three times per structure use.
- **Stream gauge:** Continuous water level measurement, of a cross section that is surveyed monthly.

Highest technically practical: Measure flow through rated gates or structures on a continuous (volumetric) basis. Due to the frequency of data points and assuming device assurance, this intensity can produce the highest level of accuracy in volumetric quantification. Different methods or procedures are used for groundwater use, crop consumption and water quality. The corresponding scenario for each location is as follows:

- **Surface water diversions:** Inventory and rate turnout structures. Install flow totaling devices, data loggers, and telemetry.
- **Groundwater use:** Totalizing flow meters coupled with an estimate of the surface runoff or deep percolation of the pumped water. Install flow totaling devices, data loggers, and telemetry. A second method is to use pump curves or pump testing and time of use. (A full description of this procedure is presented at the end of this section.)
- **Crop consumption:** Remote sensing based on a 16-day (frequency of LANDSAT 7 flyover) time step during the irrigation season with a 30-m resolution.
- **Return flow:** Inventory and rate turnout structures. Install flow totaling devices, data loggers, and telemetry.
- **Water quality:** Frequency of sampling prescribed by protocol and constituent of concern. Applies to constituents that can be measured on a continuous basis (dissolved oxygen, conductivity, pH, temperature, turbidity)
- **Farm-gate turnouts:** Inventory and rate turnout structures. Install flow totaling devices, data loggers, and telemetry.
- **Stream gauge:** Continuous water level measurement, of a rated control section consistent with the USGS criteria.

Data Collection and Management

A critical component of water measurement is the collection and management of the data generated at a measurement location. This encompasses data collection, analysis, quality control and assurance, storage and reporting. Data collection may be done locally, at a structure, or through the use of telemetry to a central collection point. Quality control and assurance are the protocols and procedures to ensure that the data is valid and represents an accurate value. Data analyses are the protocols and procedures used to answer questions or make decisions or recommendations. Storage represents where and in what format the data is kept – this also, has implications on the accessibility of the data. Finally, reporting represents the product that is made available to the end user.

Agricultural Groundwater Use

The California Department of Water Resources (DWR) estimates that groundwater provides approximately 30% of the water used statewide in the urban and agricultural sectors during an average year. During drought years, the reliance on groundwater increases. While the exact contribution of groundwater to agricultural water consumption is not known, the reliance on groundwater suggests that any attempt to define appropriate water measurement should include strategies that account for groundwater use. In this section the term groundwater refers to percolating groundwater as defined by State law. The other class of groundwater is considered subterranean streams and is legally classified as surface water.

In many areas of the State, the volume of groundwater and the level of the water table fluctuate dramatically due to natural and artificial recharge from surface runoff. In areas where the link between surface and groundwater is less direct, the available supply can be considered finite because the time period required to recharge the system is geologic in nature. Another aspect of groundwater that requires serious consideration is degradation due to the transport of natural and anthropogenic constituents.

Both the magnitude of agriculture water consumption relative to use in other sectors and the relative reliance upon groundwater supplies varies by region throughout California. In terms of the absolute level of groundwater use, four predominantly agricultural regions, the Tulare Lake Basin, the Sacramento River, the San Joaquin River and the Central Coast, account for much of the groundwater used in the State. Assuming that groundwater use is proportioned to agriculture, the same as the overall water supply, the DWR estimates that the amount of groundwater use in agriculture in these four regions, assuming 1995 land-use patterns, would be approximately 7,200 thousand acre-feet (TAF) in an average water year. During a drought year the level of groundwater use would increase to approximately 10,300 TAF. As a point of comparison, on an annual basis, the Central Valley Project has delivered a maximum of approximately 7,000 TAF of surface water while the State Water Project has delivered approximately 3,000 TAF during the same period.

The following discussion is to support the definition of appropriate measurement for agricultural water use for state water planning, allocation, transfers and water use efficiency. During previous Panel sessions, the following three options for determining groundwater use were discussed:

> **Basic:** Crop Water Balance. This approach calculates groundwater use by assuming that crop water demands not met by effective precipitation or surface deliveries are met by groundwater. This approach is currently used for the Water Plan – Bulletin 160.
>
> **High:** Hydrologic Balance. This approach calculates groundwater storage changes at the sub-basin scale by solving a mass balance of water inputs and outputs in the subsurface. In addition to the hydrologic balance, groundwater storage change is determined using a water table fluctuation method.
>
> **Highest Technically Practical:** Wellhead Extraction Measurement. This approach provides a direct measurement of groundwater pumped from a well through the installation of a flow meter or the use of a flume or weir downstream of the pump discharge. An additional method in this category is the use of a well rating based on power records and pump testing. In addition some estimate of return flow must be included.

Before discussing the mechanics and implementation of each option a general discussion of and how groundwater measurement assists the state in meeting the objectives of measurement: planning, allocation, transfers and water use efficiency is presented.

Motivation to Improving Groundwater Measurement

The section explores the connection between groundwater measurement and the stated purposes of water measurement. There are two points to consider: the benefits offered by knowing how much groundwater is used and the drawbacks if the amount of groundwater used is either unknown or subject to substantial error. Finally, due to the legal implications of personal property rights and groundwater use, the implications of measuring its use in terms of oversight, monitoring and data dissemination must be considered. This last point is particularly important, as groundwater use data is not currently collected in most regions.

Planning

Water resource planning requires an adequate level of reliable information about the amount and quality of the State's groundwater. Currently this information is collected for Bulletins 118 and 160 of the State Water Plan. The level of detail of the collected information is adequate to describe the magnitude of the resource but it is not adequate to meet the ever-demanding needs of integrated water resource planning. Information on groundwater use in the agricultural sector could benefit water resource planning at a several levels.

Planning responds to change, and one likely change is a more heavily constrained surface water supply. In this case, the State's large groundwater resource will take on increasing importance. Knowledge of historic use patterns is essential for planning potentially higher levels of groundwater use. In addition, many of the management innovations that are being contemplated to cope with the changing water supply, water demand and water regulation environment involve more coordinated utilization of surface water and groundwater supplies. These include conjunctive use, groundwater banking and water transfers. Each of these can be implemented at local, regional and statewide scales.

Local water and irrigation districts face planning obligations that could be easier to meet if the availability of information on groundwater use were increased. As such they have an oversight obligation. However, any additional groundwater information that is collected in California would add insight to statewide water planning efforts and therefore State and Federal water planners have a shared interest in overseeing and monitoring measurement data on groundwater use in agriculture. This monitoring could help assure the consistency of data that is collected and allow for the integration of measurement data collected from a variety of sources. When planning is the purpose of water measurement, data dissemination needs to be as open and transparent as possible so that the planning process can be completed with input from interested stakeholders. Adoption of water measurement for the planning purpose has the most far-reaching implications in terms of designing a system for the collection, analysis and dissemination of groundwater use and quality information.

Water Availability Determination

Water allocation is a task of the agents of State government charged with implementing the water rights system. Currently, State law recognizes groundwater as a personal property right subject to reasonable and beneficial use. In addition there are potential use restrictions when an individuals use of groundwater has negative quality or quantity affects on others. This is especially important when groundwater is substituted for transferred surface water. When groundwater is substituted for surface water the State requires that there be sufficient monitoring of the direct aquifer system to ensure that the groundwater used is not merely redirected surface water or a groundwater supply that is in use by others.

If the coordinated allocation of surface water and groundwater resources becomes an accepted strategy for meeting water demands, then information on the level of groundwater resources used by agriculture is required to prevent third party impacts. While this coordinated approach generally makes hydrologic sense, the current allocation system is limited to the management of surface water supplies. As an intermediate step between the current system and coordinated allocation, accurate knowledge of the groundwater pumping by agricultural may provide data required to identify those situations where the link between surface water and groundwater use needs to be considered.

Any necessary responsibility for oversight of measurement data on the use of groundwater would vary depending on whether groundwater was introduced into the allocation system by formal legal means or by virtue of site-specific agreements on the coordinated management of surface and groundwater. In the first case, an agent of the State would probably need to maintain oversight over measurements. In the latter case, this oversight responsibility would more logically rest with the local entity that is spearheading the coordination initiative. In the former case, the dissemination of data should be broad. In the later, decisions regarding data dissemination should be made locally.

Water Transfers

Water transfers are legal arrangements that are considered beneficial uses of water. Water transfers that involve groundwater are currently limited to groundwater substitution whereby a surface supply is transferred and the local groundwater supply is used. Currently there is no legal authority that allows for the direct transfer of pumped groundwater out of a basin. Many local water suppliers pump groundwater and introduce it into the local supply however, it may not be exported out of the system and the result of the pumping may not cause harm to local users. Specifically:

> In accordance with California Water Code Section 1745.10, groundwater substitution transfers need to be either (1) consistent with a groundwater management plan adopted pursuant to state law for the affected area or (2) approved by the water supplier from whose service area the water is to be transferred and that water supplier, if a groundwater management plan has not been adopted, determines that the transfer will not create, or contribute to, conditions of long-term overdraft in the affected groundwater basin.

When groundwater is substituted for surface water the State requires that the wells that are put into operation be monitored for their geographic location and for the amount of water pumped. The Water Transfers office of the DWR has the following position on the monitoring of water transfers:

A. Monitoring Wells

Monitoring Program Wells need to be configured with a permanent instantaneous and totalizing flow meter, access for measuring water levels, and will be free of lubricating oil in the well casing or water level sounding tube.

B. Purpose of the Monitoring Program

The Monitoring Program need to describe how the monitoring data will be collected, reported and evaluated in order to:

Quantify and verify the ground water portion of the transfer agreement.

Determine direct and residual effects of transfer pumping on the ground water basins.

Assess the occurrence of any third party impacts and, if they occur, their magnitude and significance.

Determine the surface water/ground water interactions in the areas where ground water is pumped for the transfer agreement including both pumping-induced infiltration and interception of ground-water discharge or identify a program that addresses this issue.

C. Scope and Monitoring Program Coordination with Other Efforts

The network of monitored wells needs to be sufficient to allow the evaluation of the local, regional and downstream effects of groundwater substitution transfers. The network will allow this evaluation for both areas within and areas adjacent to the well field, and allow differentiation of effects from other local and regional groundwater conditions. Similarly, the network will be such that potential third-party impacts can be identified and differentiated from seasonal or other water level changes in the basin.

The lack of information regarding the volume and availability of groundwater limits the ability of the water suppliers and farmers to optimize the use of the resource for water transfers. Currently the public information regarding well level data only provides information on the trend of the water level and not of the usable volume.

Water Use Efficiency

Meeting statewide water use efficiency objectives through groundwater use is most connected to conjunctive use management. In addition, meeting water use efficiency objectives will most likely be done at the water supplier level. Through conjunctive use, water managers use facility options that most effectively meet their customer's needs and their contractual contribution to the stated objectives. Knowing the volume of water pumped or the available supply allows the local agency to effectively manage their system.

Information on the amount of groundwater pumped and of the of the aquifer is required when balancing available water supplies with consumptive demands. During periods of inadequate surface water supplies, information on the availability of groundwater becomes more important. Having a record of the amount of groundwater that is used, under a variety of climatic and water supply scenarios would help water managers plan for the use of this resource.

Groundwater Measurement Options

Determining the volume of groundwater used by irrigated agriculture can range from the current approach (Option A) to totalizing wellhead meters, coupled with an estimate of return and deep percolation flows. Defining an appropriate strategy for estimating agricultural groundwater use depends on several factors, most importantly the stated purpose of agricultural water measurement. The background materials prepared for the panel identified the three options defined below

Basic: Crop Water Balance

This strategy for estimating agricultural groundwater use involves the assumption that any crop water deficit remaining after accounting for effective precipitation and the application of surface water is made up with groundwater. When the appropriate data is available, this method can be applied to management units ranging in size from a single land-use unit or field to the collections of fields within a larger administrative boundary. This method is based on numerous assumptions that impact its accuracy. This method is currently used, on an annual basis, by the DWR at the level of the Detail Analysis Units (DAU).

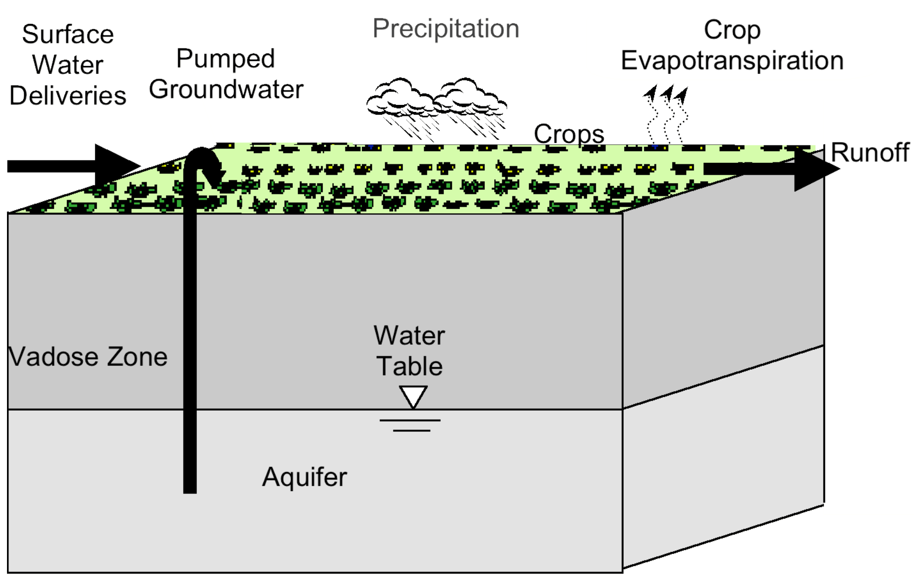

FIGURE 5.1. Option A for estimation of groundwater use. This method is based on the assumption that any crop water deficit, after accounting for effective precipitation and applied surface water, is made up with groundwater.

These estimates of groundwater use are rough because, outside of a few adjudicated or managed groundwater basins, there is no requirement to directly measure groundwater use and therefore no independent check on the method. Groundwater use is estimated for 278 DAU that are generally defined by hydrologic features or boundaries of water service agencies. In the predominantly agricultural regions, the DAU generally encompass between 100,000 and 300,000 acres. For each DAU the DWR estimates groundwater use with by:

1. Developing estimates of crop water consumption based on land use surveys that are done over five years and applying crop coefficients and real time climatic information,
2. Adjust the crop water consumption by accounting for effective precipitation and
3. Obtain surface water delivery information
4. Attribute the unmet crop water consumption to groundwater.

An improvement to this method would be the use of remote sensing to collect land use and actual evapotranspiration (ET) information. To generate a consumption estimate, each remote sensing event is coupled to an evapotransporation estimate generated at a CIMIS station. The resolution of the remote ET estimate is a function of the frequency of data collection. Imaging done on crop growth basis such as pre-season, initial canopy cover, full cover and senescence will provide an accurate estimate of the annual ET. Another benefit of using remote sensing is that it ensures a more complete and up-to-date cropping coverage.

High: Hydrologic Balance

This approach calculates groundwater storage changes at the sub-basin scale using two methods; by solving a mass balance of water inputs and outputs in the subsurface and water-table fluctuation method.

Irrigators in agriculturally-intensive groundwater sub-basins often rely on a combination of imported and local surface water supplies and pumped groundwater to meet their crop water demands. While records of surface water diversions to water service areas (e.g. irrigation districts, water districts, public utility districts) are generally quite reliable, groundwater pumping records are often not regularly maintained or made available to the public. As a consequence, groundwater used for agricultural purposes must often be estimated by a model. Frequently, groundwater pumping is estimated as a closure term in a crop water balance model (Option A). There, pumping is computed as the balance of the crop water demand not met by applied surface water, effective precipitation, and soil moisture. Unfortunately, no other straightforward estimators of groundwater pumping are available to independently evaluate the quality of the crop water balance estimates.

Although groundwater pumping estimates are difficult to evaluate, groundwater storage changes in the aquifer system can be estimated using two approaches: 1) a hydrologic balance model, and 2) the water-table fluctuation method. The hydrologic balance model computes storage changes at the sub-basin scale by solving a mass balance of water inputs and outputs in the subsurface. The water inputs often include deep percolation from applied irrigation and infiltrated precipitation, seepage from natural and constructed surface water channels, and inter-basin groundwater inflow; and the outputs are groundwater pumping, return flows to surface water channels, and inter-basin groundwater outflow. The water-table fluctuation method computes storage changes as a function of hydraulic head differences and unconfined aquifer specific yield.

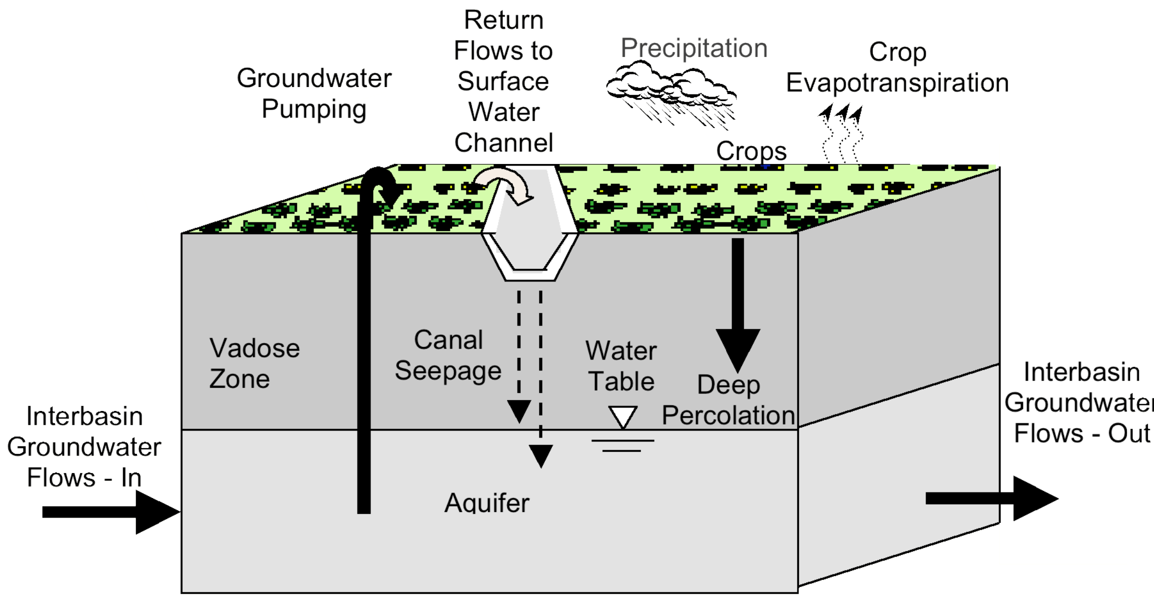

FIGURE 5.2. Option B(1) - Hydrologic Balance Model is for estimating groundwater use. This approach computes storage changes at the sub- basin scale by using a mass balance of water inputs and outputs.

Unless directly measured, the input and output components for the hydrologic balance model must be estimated from other sub-models. For example, groundwater pumping is still estimated using a crop water balance model, whereas channel seepage and groundwater return flows are estimated by a surface water balance model. However, in the process of determining all the components used to estimate storage changes by this approach, a complete hydrologic balance for the sub-basin is performed. The quality of the groundwater pumping estimates, as well as those of the other hydrologic balance model components, can be indirectly evaluated by comparing the overall storage changes between the two independent approaches.

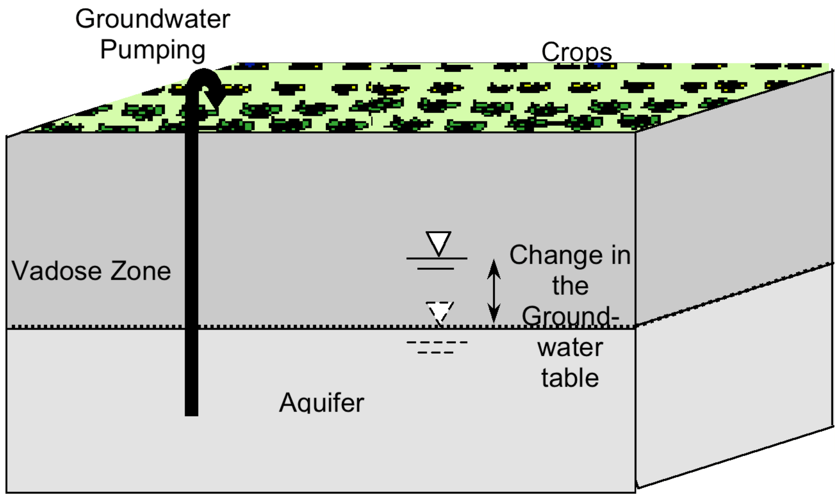

FIGURE 5.3. Option B(2) Water Table Fluctuation Method for estimating groundwater use. This approach computes storage changes as a function of hydraulic head differences and specific yield.

The hydrologic balance model and the water-table fluctuation method are only estimators of groundwater storage change. Since the actual storage changes are unknown, the discrepancies between the two models and reality can never be assessed. Despite this limitation and the potential sources of error in both methods, agreement between them does provide confidence in their abilities to independently estimate storage changes. Taken together, their results may provide a range of expected groundwater storage changes on the sub-basin scale as well as an indirect method for evaluating the reasonableness of the model components (e.g. groundwater pumping) used to estimate these changes.

Using a hydrologic balance model groundwater storage changes are estimated by solving a mass balance of water inputs and outputs in the aquifer system. The water inputs may include deep percolation from applied irrigation and infiltrated precipitation, seepage from natural and constructed surface water channels, and inter-basin groundwater inflow. The outputs may include groundwater pumping, return flows to surface water channels, and inter-basin groundwater outflow. Drain flows might also be another output in some sub-basins.

A crop water balance model is required to provide estimates of groundwater pumping and of deep percolation from applied irrigation and infiltrated precipitation. The crop water balance model solves a mass balance of water inputs and outputs in the soil root zone. The inputs include applied irrigation and infiltrated precipitation, and the outputs include crop evapotranspiration and deep percolation of excess applied irrigation and precipitation. Bare-soil evaporation in fallow and undeveloped lands is another potential output in the model. Another approach to determining crop water consumption is the use of actual evapotranspiration obtained through remote sensing. This approach is discussed further in the section on crop water consumption.

A surface water balance model is required to provide estimates of seepage from natural channels (e.g. rivers, creeks) and unlined conveyance channels (e.g. ditches, canals) and of groundwater return flows. The surface water balance model solves a mass balance of inflows and outflows along the reaches of each major channel in the sub-basin conveyance network. Seepage is often estimated as a closure term in the surface water balance for each channel reach. These reaches are delimited by the locations of consecutive flow gauging stations. For many channels, only inflow data (e.g. metered diversions, gauged flows) is available. Consequently, seepage losses in those channels are often estimated as a percentage of measured inflows. Channel seepage is a significant source of aquifer recharge in many agricultural areas practicing conjunctive use. Groundwater return flows to surface water channels are generally difficult to estimate but may be assumed negligible for many natural channels located in agriculturally-intensive sub-basins in the state.

Inter-basin groundwater inflows and outflows are also difficult to estimate. Coarse estimates can be obtained by applying Darcy's Law across the vertical boundaries between adjacent sub-basins. This calculation requires values for the hydraulic head gradient across the vertical boundary, the inter-basin hydraulic conductance, and the cross-sectional area of the aquifer system through which groundwater flows. Net sub-basin groundwater inflows may be negligible for large sub-basins which behave approximately as closed systems.

The water-table fluctuation method is a technique which computes local unconfined and semi-confined aquifer groundwater storage change as a function of the hydraulic head difference between different measurement periods and the unconfined aquifer specific yield. The water-table fluctuation method is not appropriately applicable for confined aquifer systems where groundwater storage changes are a small fraction of those in unconfined or semi-confined aquifers. The estimated groundwater storage changes in an unconfined or semi-confined aquifer at the local scale can be spatially aggregated to provide an estimate of storage change at the sub-basin scale.

Currently, the Department of Water Resources collects bi-annual (spring and fall) measurements of hydraulic head from production wells distributed throughout the state. These water levels are used in the water-table fluctuation method to estimate seasonal (i.e. spring to fall) or annual unconfined aquifer groundwater storage changes. The quality of the hydraulic head measurements and the conditions under which they were obtained are not completely known. These data may represent ambient water levels in production wells not in use at the time of measurement or wellbore drawdown recovery in wells recently pumped. Moreover, the spring and fall measurements each are obtained annually over a 2-4 month period (e.g. spring measurements taken from early-January to late-March). For these reasons, the observed hydraulic heads are not strictly considered a reliable measure of the water levels in the aquifer formation away from the production wells in which they were obtained for any given year. However, if the measurements in a well for consecutive years were obtained under similar pumping and recovery circumstances, then the head difference between years can be used to infer groundwater storage changes rather than a single year measurement representing actual formation groundwater levels.

The specific yield on the local scale can be estimated either by performing an unconfined aquifer pumping test or by a textural analysis of well logs. In published studies, specific yield has been correlated with aquifer sediment texture. The delineated depth intervals in well logs are assigned specific yield values as a function of their assigned textural descriptions. The depth-weighted arithmetic average of the well log specific yield values is used as an effective specific yield of the aquifer formation on the local scale. The benefit of using two independent methods of calculating groundwater storage changes is that the methods can be compared against one another (Figure 5.4).

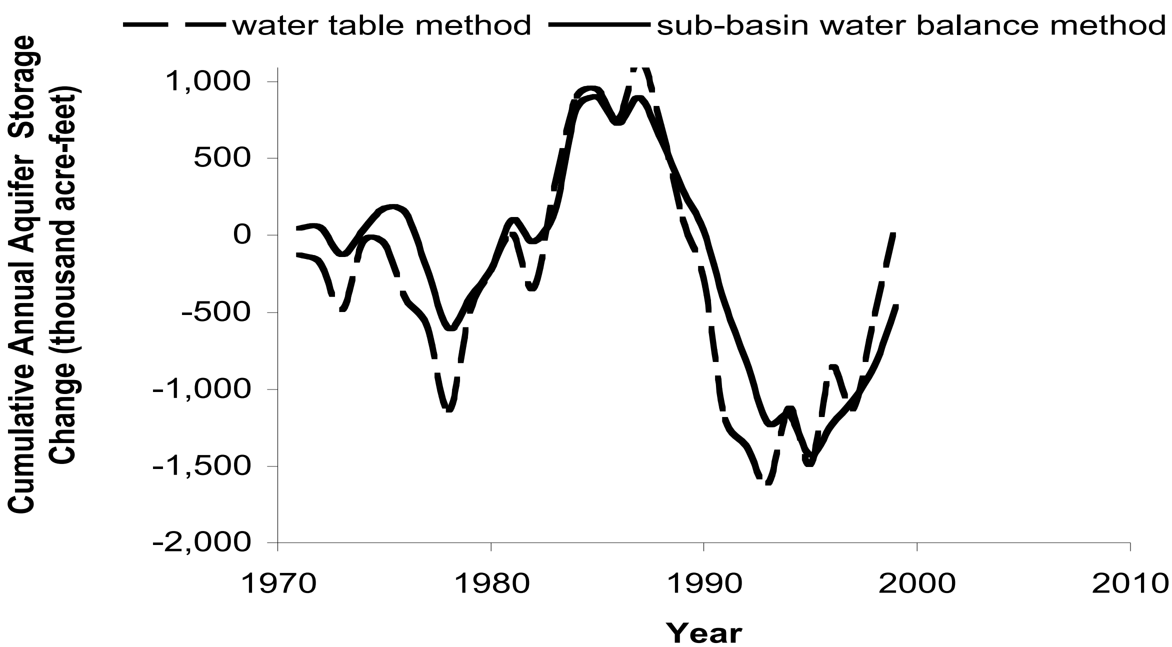

Figure 5.4. Comparison of the two methods used for Option B; sub-basin hydrologic balances and water table fluctuation method.

Model Data Measurement Scale and Database Management

The purpose of this option is to quantify groundwater pumping and groundwater storage changes at the sub-basin scale. However, the available data used to quantify the various parameters in the hydrologic balance model and the water-table fluctuation method are often measured at different spatial and temporal scales of resolution. Parameter data may be measured at daily, monthly, or annual time steps. Data may also be distributed spatially as points (e.g. precipitation gauging stations), lines (e.g. channel seepage), or areas (e.g. land units in a land use survey). For example, surface water channel seepage is a localized source of aquifer recharge quantified at a lineal scale whereas deep percolation of applied irrigation and precipitation is a diffuse source of recharge quantified on an areal scale. Data are also often reported in different units of measurement, georeferenced coordinate systems, and database structures (e.g. spreadsheet, hard copy reports). These issues can be mitigated by managing the model data in a geographic information system (GIS). Differences between the measured scale and the modeled scale can be resolved using the spatial overlaying and interpolation capabilities of the GIS. The eventual estimates of sub-basin groundwater pumping and groundwater storage change are obtained using the GIS to spatially aggregate the results of the hydrologic balance model and the water-table fluctuation method from their respective modeled scales to the sub-basin scale.

Model Data Quality

As mentioned above, the data used to develop the hydrologic balance model and the water-table fluctuation method are measured at different spatial and temporal scales of resolution. The quality of the data is determined by the ability of their measurement scales to adequately represent the relevant hydrologic processes at the modeling scale. For Option B, the modeling spatial scale is the land unit and the temporal scale is monthly. The results of the model are aggregated to the sub-basin scale on an annual basis.

The amount of applied irrigation is theoretically estimated by a crop water demand model. The source of applied irrigation for most sub-basins is typically surface water and groundwater. Monthly imported and local surface water supplies for individual water service districts are often well documented.

Groundwater pumping estimated by the crop water balance model is aggregated from the land unit to the sub-basin scale. The upper-bound on the estimates of monthly total groundwater pumping at the sub-basin scale is the difference between the monthly available surface water and the monthly total crop evapotranspiration in the sub-basin.

Crop evapotranspiration is also estimated by a crop water demand model. Monthly crop evapotranspiration on the land unit scale can be estimated indirectly using crop coefficients, a reference crop evapotranspiration rate, and the land unit acreage. Crop coefficients for different geographical areas are available in the CIMIS database. Reference crop evapotranspiration rates are also measured at various CIMIS weather stations located throughout the state. The distribution of the major crops on a land unit scale can be obtained from county land use surveys. Crop evapotranspiration can be computed at the land unit scale and aggregated to provide estimates of crop consumptive use at the sub-basin scale.

Precipitation is measured at gaging stations discretely located throughout the state. Time-series of precipitation from these stations are used to generate isohyet maps which coarsely characterize its spatial and temporal distribution. Precipitation falling on the ground surface either evaporates back into the atmosphere, leaves the area as run-off, or infilitrates into the subsurface. The precipitation that infiltrates into the subsurface is partitioned as effective precipitation and as deep percolation below the soil root zone. Effective precipitation refers to the soil moisture derived from precipitation that satisfies a percentage of the crop water demand. Deep percolation of infiltrated precipitation below the root zone is assumed to eventually recharge the underlying aquifer system. For large sub-basins, run-off of precipitation can be assumed negligibly small.

Channel seepage in the natural and constructed channels can be estimated by a performing a mass balance of inflows and outflows, if these data are available.

Reliable measurements of inflows and outflows along stretches of some of the major natural channels (e.g. Kings River) are available. The seepage loss rates determined from them can be used to estimate seepage losses in channels for which only measured inflow data are available. As mentioned previously, measured inflows of local and imported surface water in the major channels are generally well documented.
Inter-basin groundwater inflows and outflows no doubt occur through the sub-basin boundaries. For a large sub-basin, however, these flows are likely small in comparison to the total changes in groundwater storage due to vertical stresses applied within the sub-basin interior (e.g. groundwater pumping, evapotranspiration, applied surface water, channel seepage). Horizontal groundwater flow at the inter-land unit and inter-district scales is expected to be more significant. However, for the sub-basin scale hydrologic balance it can be assumed that most large sub-basins behave as relatively closed systems with negligibly small net inter-basin groundwater inflows through their vertical boundaries.

Highest Technically Practical: Wellhead Extraction Measurement
This approach uses a direct measurement or estimate of the amount of groundwater pumped. Direct measurement of groundwater pumped from a well through the installation of a flow meter is a high-end option for quantifying the level of water pumped. There is a wide array of in-line flow meters that can be installed at the wellhead. A second direct measurement option is to use a weir (inclusive of measurement) downstream of the pump discharge, however the cost for this would be much greater than an inline flow meter.

Another wellhead method that would provide an estimate of the amount of groundwater pumped is to test the well and pump and relate the test results to a pump factor that can then be used to estimate the volume of water pumped. A pump factor is developed based on a pump test that uses three operating parameters for a pumping plant: the total dynamic head, the total flow being pumped, and the power consumption. Once a pump test has been done the pump factor is used to describe the volume of water pumped for a given amount of power consumption. However, this strategy only allows for an estimation of groundwater pumping where and when the results of a valid pump test, and a record of power consumption are available. In addition the test result relies in part on the continued performance of a mechanical device that is subject to degradation over time. Regardless of the wellhead method used, in order to determine the net groundwater use, an estimate of the amount of pumped water that is returned through deep percolation or surface runoff is required.

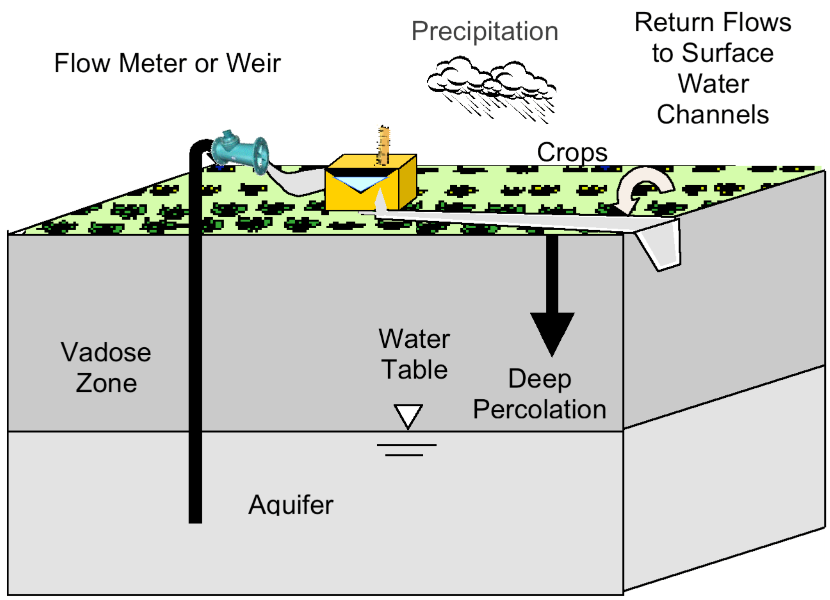

FIGURE 5.5. Option C Wellhead Extraxction Method for estimating pumped groundwater. Quantifying the amount of water pumped through direct measurement by totalizing flow meter or through the use of a weir downstream of the pump discharge. To get net groundwater use a method to estimate deep percolation or surface runoff is required.