Conceptual Design of a Conjunctive Management Project

Nebraska Department of
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1.0 Introduction and Background

The objectives of this study were two-fold: 1) identify general elements, potential approaches, and constraints necessary in the planning and evaluation of conjunctive management projects, and 2) evaluate several hypothetical conjunctive management strategies involving the Western Canal to illustrate the application of these concepts. While the case study of the Western Canal is specific, the elements, approaches and constraints described in this document have broader application to other basins and potential conjunctive management projects.

1.1 Conjunctive Management

Conjunctive management typically refers to the coordinated and planned use and management of both surface water and groundwater resources to maximize the availability and reliability of water supplies in a region to meet various water needs.[1] Surface water and groundwater resources typically differ significantly in their availability, quality, management needs, and development and use costs. Managing both resources together, rather than in isolation, allows water managers to use the advantages of both resources for maximum benefit.

Conjunctive management thus involves the efficient use of both resources through the planned and managed operation of a groundwater basin and a surface water storage system and/or conveyance infrastructure. Water is stored in the groundwater basin for later and planned use by intentionally recharging the basin when excess surface water supply is available, for example during years of above-average surface water supply.

The necessity and benefit of conjunctive water management are apparent when surface water and groundwater are hydraulically connected. Well planned conjunctive management can not only increase the reliability and the overall amount of water supply in a region, but also provide other benefits such as flood management, environmental water use, and water quality improvement. Greater benefit can usually be achieved when it is applied to multiple regions or statewide. Examples of conjunctive water management include:

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[1] Coe, JJ, provides following definition: “Conjunctive use of surface and groundwaters can be defined as the management of surface and groundwater resources in a coordinated operation to the end that the total yield of the system over a period of years exceeds the sum of the yields of the separate components of the system resulting from an uncoordinated system.” Journal of Irrigation and Drainage Engineering, 116, 3, pp 427-443, *Conjunctive Use – Advantages, Constraints, and Examples*, 1990

Tamarack Project, Northeastern Colorado[2] – The Tamarack project in northeastern Colorado is a conjunctive management project that intentionally recharges South Platte River flows during low demand periods (October to March). Recharged flows return to augment South Platte River flows during higher demand periods (April to September), allowing junior groundwater users to irrigate without impacting senior surface water appropriations.

Tacoma, Washington[3] – The Green River is the principal water source for the City of Tacoma and typically requires minimal treatment. Seasonally, the Green River has periods of excessive turbidity – typically during the spring snowmelt runoff. During this time, the City augments the water supply with groundwater, blending the Green River and groundwater to lower turbidity to an acceptable level without addition of supplemental treatment processes.

Phoenix, Arizona[4] – The metropolitan area of Phoenix conjunctively manages multiple sources - surface water, groundwater, imported water, artificial recharge, and reclaimed wastewater - to meet historic agricultural demands and the growing municipal and industrial needs.

A sustainable conjunctive water management program consists of several components that include investigating the groundwater aquifer characteristics, estimating surface water and groundwater responses, and appropriate monitoring of groundwater level and quality. In addition, reliable institutional systems for ensuring environmental and regulatory compliance, providing long-term system maintenance, and managing contractual and legal features of the program are critical to sustainability.

2.0 Water Supplies and Uses

Characteristics of surface and groundwater supplies and uses typically have significant differences in temporal distribution, spatial distribution, management needs, level of development, and costs. Defining these water budget components for the area of interest is a key first step in the development of a potential project and necessary to estimate timing, availability, and quantity of water available to manage conjunctively.

The evaluation of a conjunctive management project requires the identification, collection, and consideration of data relating to the proposed site in conjunction with the related surface and groundwater resources. The datasets and site considerations described in this section are not to be considered all-inclusive, but represent key elements required to initiate the planning and evaluation

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[2] Platte River Recovery Implementation Program, Attachment 5 – Section 3 *Colorado's Initial Water Project (Tamarack I)*, 2006

[3] USACE Research Document No. 27, *Elements of Conjunctive Use Water Supply*, 1988.

[4] Arizona Department of Water Resources, *Third Management Plan for Phoenix Active Management Area 2000-2010,* 1999.

process. Fortunately, much of the data is readily available as noted from previous and current water supply planning efforts being conducted by Nebraska surface and groundwater management authorities.

2.1 Water Supplies

2.1.1 Surface Water Supplies

Surface water supplies are principally derived from precipitation runoff less evaporative losses. Typically surface water flows are available seasonally but vary significantly in the time and amount available. Storage reservoirs are often constructed as a means to smooth temporal variations in surface water supplies and improve reliability.

Available surface water is often determined based on historical stream gage and diversion records. This historic record can be used as is or adjusted based on future supply expectations. Statistical methods, such as a Kendall Tau test, are often used to detect if trends in the historic gage data exist and if adjustments to the estimated future supply are warranted. If a trend exists, or future variables can be calculated (i.e. lag depletions from groundwater pumping, shifts in long-term precipitation trends, etc.), it may be desirable to utilize a subset of the historic record or adjust the historic record so that it best represents typical or expected future conditions.

One alternative to direct use of the historic record may involve using the historic record to develop a flow duration curve representing relative frequency of expected flows. The flow duration curve can then be used to estimate reliability of surface water supplies and reflect the variability in expected supplies. This is often critical in determining whether a project is viable or predicting ultimate project benefits.

2.1.2 Groundwater Supplies

Groundwater supplies typically found in large aquifer formations exhibit considerably less variation in temporal and spatial distribution than surface water supplies. Aquifers are recharged from natural precipitation infiltration, applied irrigation infiltration, and seepage from lakes, reservoirs, streams, and canals.

The interaction between surface water and groundwater supplies are largely dependent on the underlying aquifer characteristics and play a critical role in the development of conjunctive management projects. This interaction is represented by flow of groundwater supplies to receiving streams and conversely from surface water supplies to the aquifer.

The key aquifer characteristics that dictate the surface water and groundwater interaction, and ultimately the groundwater supply are the depth to groundwater and overall aquifer depth, infiltration and seepage rates, and hydraulic conductivity and storage parameters of the aquifer.

Depth to groundwater and aquifer depth information is typically readily available from United States Geological Survery (USGS) and Natural Resources District (NRD) monitoring well sites. This data is often adequate for planning purposes, however, often these values are general estimates. In locations where large fluctuations in groundwater can be anticipated, variations in the groundwater elevation should be measured throughout the year at nearby wells. If no monitoring well is within the vicinity of the project, installation of additional monitoring wells may be required. The depth to groundwater dictates the ability of flows to infiltrate, in addition to defining the active aquifer storage volume available for groundwater recharge. Generally, depths to groundwater in excess of ten (10) feet are desirable to prevent interference with infiltration and high groundwater elevations impacting land use such as crops and farming operations, as well as existing infrastructure (roads, building sites, basements, etc.).

The soil type and gradation determine the infiltration rate of the recharge facility and therefore, directly impact the required size of recharge facilities. Soil survey data from the Natural Resources Conservation Service (NRCS) database is readily available and identifies prevalent soil types as well as characteristics of those soil types. Estimates of infiltration rates based on soil types can be developed based on previous studies or published estimates by soil type classification. Percolation tests may also be conducted and provide quick and cost-effective verification to infiltration estimates.

Hydraulic conductivity is used to estimate rates of groundwater movement and is used in evaluating the aquifer-stream interaction. Hydraulic conductivity and storage parameters may be estimated through published values based on aquifer strata or through field pump tests.

Aquifer-stream connectivity is key in estimating impacts of conjunctive management strategies on surface water and groundwater supplies. Stream depletion factors (SDFs) are commonly used to represent aquifer-stream connectivity. SDF estimates can often be obtained from general mapping developed in previous studies. Analytic methods, such as those developed by Jenkins, may also be used to estimate this interaction. In areas where numeric groundwater models have been developed, SDFs can be readily developed for the project vicinity. The level of refinement necessary for utilizing a given stream depletion factor is typically dependent on the temporal resolution necessary for meeting the conjunctive management objectives (i.e. intra-annual, fifty-year planning horizon, etc.)

2.2 Water Uses

Conjunctive management projects, by their very nature, include surface water and groundwater components that are linked within the hydrologic cycle. This linkage requires that water supply uses be identified and quantified for evaluating potential project impacts. Depending on the project some uses may be directly impacted by the project and are involved in the yield calculations, while others may be indirectly affected by the resulting changes in the water budget and must be considered.

2.2.1 Agricultural

Many potential groundwater recharge projects involve modifying current surface water and groundwater supplies used for irrigation. Applied irrigation may be partitioned into consumptive use, runoff, and infiltration. Accurately identifying irrigated acreage associated with the potential project is then a fundamental requirement. The surface water irrigated acreage can be obtained from the surface water appropriation database of the Nebraska Department of Natural Resources (NDNR). In addition, co-mingled acres (those with surface and groundwater sources available) should be identified. Information on groundwater irrigated acreage can be obtained from the NDNR database of registered wells. In addition, many NRDs have well and groundwater irrigated acreage datasets than can be used. While these data sets have limitations (i.e. do not represent actual irrigated acres in a given year) they are a good starting point to initiate the planning and evaluation process. Data for Nebraska collected by the United States Department of Agriculture (USDA) as part of the National Agricultural Census may better represent annual irrigated acres on a county-wide basis.

Estimates of crop consumptive can be made based on published data specific to crop type, soil type, and climatic conditions, either from generalized mapping, or more detailed consumptive use models such as CROPSim[5]. Many potential groundwater recharge projects involve modifying current canal operations involving surface water irrigation deliveries.

Runoff can be estimated from gage data when available. Analytic and numerical watershed modeling techniques may also be employed to predict runoff. Finally, infiltration rates can be estimated using published values, or by analytic methods such as those developed by NRCS.

Losses associated with surface water delivery systems (reservoirs, canals, and laterals) for agricultural usage consist of evaporation, seepage, and surface water returns to streams. Evaporation estimates can be developed based on evaporation data collected at National Weather Service or National Climatic Data Center recording stations. Seepage and surface water returns vary by canal and are dependent on canal operations. Synoptic studies of canal reaches using measured flows at the upstream and downstream limits and gaged diversion data from within the reach can be used to estimate seepage rates and return flows to the stream. Additional data can often be garnered through interviews with canal operators.

2.2.2 Domestic Use

Domestic water usage data is often unavailable as individual wells are typically not metered. An estimate of domestic water usage can be developed based on registered domestic well data or United States Census Bureau data and published per capita estimates of use and consumptive use. In Nebraska, domestic wells were not required to be registered until 1993; therefore, there are limitations on the accuracy of that data, the United States Census Bureau data may be a more reliable source of data for population estimates.

2.2.3 Municipal and Industrial

Municipal and industrial users are typically served by utilities that provide potable water supply and process wastewater prior to returning it to the receiving stream. Historic utility records may be used to estimate both consumptive use and treated wastewater returns. In the absence of utility records, regional or national estimates of per capita consumptive uses may be used.

2.2.4 Hydropower

Hydropower delivery and returns typically have established gaging stations nearby with records that can be used to estimate total water delivered to the hydropower facility as well as water returned to the

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[5] Computer simulation model developed at the University of Nebraska-Lincoln by Dr. Derrel Martin for use in computing daily soil water budgets for crops typically grown in the State of Nebraska.

stream. In addition, operational records of the hydropower facility are typically maintained by the owner. Together these can be used to estimate consumptive use of hydropower generation.

2.2.5 Instream Flows

Instream flows are non-consumptive uses that must be considered in determining available water supplies. Instream flow appropriation data, available from NDNR, contains information on the location, time, and quantity of instream flows.

2.2.6 Recreation

Recreation use is another non-consumptive use that carries economic and social value. Minimum flows or stages for viable recreation usage can be collected from facility operators and entities, such as the Nebraska Game and Parks Commission.

3.0 Conjunctive Management Project Components

Conjunctive management projects generally include three primary components: 1) Diversion of surface water; 2) Recharge facilities; and 3) Use of the water, which may include the management of return flows.

3.1 Diversion of Surface Water

Typically, diversion of surface water for groundwater recharge projects is accomplished using existing diversion structures or newly constructed diversion structures built as part of the project. Shallow alluvial wells immediately adjacent to the river can also be used to capture surface water flows.
The primary operational characteristic of the proposed project as it relates to available water supply is the duration of the diversion season.

The anticipated duration of the diversion season for the project must consider the use and diversion season restrictions of the appropriation, the availability of water, and increased operation and maintenance for the project if the diversion season is extended. Project sponsors must balance the additional water supply typically available in the early spring (March - April) and late Fall (November-December) with the potential increased operation and maintenance costs due to the extended diversion season and possible damage from ice.

Anticipated surface water deliveries for the project must be defined in addition to the use of those deliveries. This may include making full surface water deliveries, no surface water deliveries, or partial surface water deliveries.

3.2 Recharge Facilities

Recharge can be accomplished by several methods and often depends on several factors, such as water source, water quality, type of aquifer-stream interaction, site conditions, soil types, and economic considerations. Spreading water to encourage infiltration is the most widely used method. Facilities may include long linear features, such as existing canals, laterals, wasteways, and channels, small reuse pits, large recharge basins, or a combination. Direct discharge to the aquifer using natural openings, constructed shafts or recharge wells is another method commonly used.

The required size of the recharge facility can be approximated using estimated infiltration rates and volume of water available for recharge to compute the required areal extents of the recharge facilities. The computed areal extent should be adjusted for contingencies such as related infrastructure and periodic maintenance to estimate the land acquisition required for the project. Multiple recharge facilities provide flexibility in the operation of the project and redundancy in case of unforeseen maintenance issues or the availability of larger volumes of water.

Existing infrastructure in the project vicinity should be inventoried to identify opportunities for utilizing existing facilities to the extent possible, in addition to identifying potential constraints to the recharge facilities. Relevant infrastructure includes:

- Existing conveyance facilities, reuse or storage pits, and adjacent wells that could be used in the configuration of the groundwater recharge project. Typically this information can be gathered from facility operators, from aerial and topographic mapping, and from site visits.
- Roads, irrigation pivots, parcel ownership boundaries, power lines, and utilities that may constrain siting of the recharge facility.
- Road and railroad embankments, houses and building sites, and lowland meadows or agricultural fields that may be susceptible to high groundwater tables

Typically, the majority of this information can be gathered from project sponsors, from facility operators and customers, from aerial and topographic mapping, and from conducting field visits.

3.3 Existing Uses, Planned Uses, and Management of Return Flows

Existing uses may stay the same, increase or be reduced. Planned uses could include irrigation, industrial, municipal, hydropower, etc., depending on the project goals. In many projects, flows of surface water and groundwater to the river are an important component of the project goals. Returns flows to the river can be actively or passively managed, with the method employed largely dependent on the project goals. Active management generally includes recovery through pumping of groundwater directly to the river and is effective in meeting flow needs at specific times for specific durations. Passive management uses groundwater return flows to the river and is typically used to meet annual or long term flow targets.

3.4 Western Canal Conjunctive Management Project Scenarios

The types of conjunctive management projects addressed in the Western Canal study involve: 1) the diversion of surface water supplies using existing or new diversion facilities, when available;
2) intentional groundwater recharge using existing canals and reuse pits, as well as constructed recharge basins; and 3) long term groundwater return flow to offset depletions due to groundwater pumping.

4.0 Benefits/Considerations for Evaluating Projects

Project stakeholders ultimately must weigh many considerations in deciding the viability of a conjunctive management project and selecting alternative configurations of the project. Table 1 provides an example matrix of project impacts that can be used as a tool for screening conjunctive management project alternatives. Sections 4.1 through 4.4 describe some of these considerations in greater detail.

Table 1: Matrix for Evaluating Project and Comparing Alternatives

Project Impacts	**Alternative 1**	**Alternative 2**	**Alternative 3**	**Alternative n**
Availability of water supplies in region				
Reliability of water supplies in region				
Agricultural Use				
Domestic Use				
Manufacturing and Industrial Use				
Hydropower Generation				
Recreation Use				
Instream Flow Use				
T&E Species				
Fish and Wildlife Habitat				
Wetlands				
Historical Resources				
Cultural Resources				
Air Quality				
Water Quality				
Prime Farmland				
Irreversible Use of Resources				
Public Safety				
Real Estate Tax Base				
Additional Impacts as Needed				

For each Alternative, the potential impacts can be rated qualitatively (with +++ or ----), with generalized descriptions, or with actual values if available. Even a rating of "No Change" will help in the decision making process. For some features the Short Term impacts and the Long Term impacts may be different and should be identified. Once the potential alternatives are narrowed down to a workable group, more detailed analysis can be performed on key impacts such as cost, economics, water yield, etc.

4.1 Water Yield

Many conjunctive management projects are focused on maximizing the availability and use of water resources. Water yield is a useful metric to measure the project ability to meet this goal.

4.1.1 Increased Water Availability

The ability to move water between storage facilities, generally surface water to groundwater storage facilities, reduces non-beneficial losses such as evaporation resulting in an increase in total water availability. The overall quantity of water available for use increases due to conjunctive management.

4.1.2 Improved Operational Flexibility and Reliability

Conjunctive management allows the capture of water during times of surplus supply for beneficial use during times of shortage. Fluctuations in supply prevalent in the natural system are dampened, reducing the risk of shortages, and providing increased reliability.

4.1.3 Project Yield Computations

Calculating the impacts to the local water budget components is necessary to determine the net yield of a conjunctive management project. The computation of project yield for a potential project whose goal is to maintain or improve river flow conditions requires estimation of five quantities:

1) Computed recharge returns (groundwater) to the river of the proposed project;
2) Computed returns/spills (surface water) to the river of the proposed project;
3) Computed depletions to the river based on additional pumping to replace lost surface water supply;
4) Computed baseline recharge returns (groundwater) to the river based on historic operations of the canal system; and
5) Computed baseline returns/spills (surface water) to the river based on historic operations of the canal system.

Combined, the following equation applies and compares the local water budget under current and proposed conditions:

Net Yield to the River =
(Recharge returns of Proposed Project) + (Returns/Spills of Proposed Project)
– (Depletion of Replacement Pumping) – (Baseline Recharge Returns) – (Baseline Returns/Spills)

Depending on the goals defined for the project, the yield accounting can be done on a monthly, seasonal, or annual basis. Sections 4.1.3.1 through 4.1.3.5 expand on each of the terms of this equation. For other goals, different water yield calculations may be necessary.

4.1.3.1 Recharge Returns of Proposed Project

Recharge returns of the proposed project are estimated from the recharge water supply and the aquifer connectivity to the river. The recharge water supply can be estimated from the available surface water supply for the project, adjusted for estimated spills and returns, evaporation/evapotranspiration (ET) losses, and surface water deliveries, if any. The aquifer connectivity can then be used to predict the timing and volume of recharge returns reaching the river.

4.1.3.2 Returns/Spills of Proposed Project

Returns and spills from the proposed project, unlike ET losses and surface water deliveries, are flows that return to the river and are credited to the project yield. Typically, the intentional recharge facilities are sized with redundancy such that there is sufficient capacity for all diverted flows - therefore returns and spills of the proposed project can many times be assumed to be negligible. For cases where returns or spills are anticipated the quantities should be estimated and can be assumed to reach the river in the same time increment in which they were diverted for yield accounting purposes.

4.1.3.3 Depletion of Replacement Pumping

In cases where surface water deliveries will cease under the proposed project, users may offset lost surface water supplies with groundwater supplies through replacement pumping. This replacement pumping will result in some depletion to flows in the river. The calculated depletion volume and timing due to replacement pumping depends upon pumping volume, rate, and stream-aquifer connectivity.

4.1.3.4 Baseline Recharge Returns

Baseline recharge returns of current system operations are estimated from the historic diversion record, the estimated seepage volumes, and the aquifer connectivity to the stream. The stream-aquifer connectivity can then be used to predict the timing and volume of baseline recharge returns reaching the river under current and historic canal operations.

4.1.3.5 Baseline Returns/Spills

The baseline returns and spills of current operations are estimated from the historic diversion record and the estimated returns and spills. Baseline returns and spills should be estimated for current and historic canal operations and may be assumed to reach the river in the same time increment in which they were diverted for yield accounting purposes.

4.2 Water Quality

Conjunctive use projects result in the blending of water from surface and groundwater sources which often differ in quality. Intentional and unintentional impacts of a proposed project to surface and groundwater quality must be considered.

4.2.1 Surface Water Quality

Intentional recharge of surface waters reduces the amount of streamflow, potentially reducing dilution to pollutants entering the stream from downstream sources. Groundwater return flows, either passively or actively managed, could also introduce new pollutants (arsenic, iron, etc.) to the receiving stream. For streams with defined numeric pollutant standards, the potential impacts of reduced dilution must be evaluated. Potential impacts should be evaluated by assessing the post-project timing and quantity of streamflows, in conjunction with pollutant concentrations and loadings, at critical locations with numeric thresholds. Groundwater return flows, either passively or actively managed, could also introduce new pollutants to the stream

In cases where the quality of surface water to be used for recharge is severely degraded, the filtering effect of the aquifer may result in groundwater returns of increased water quality. It should be noted that the filtering capability of the aquifer is finite in its ability to absorb organic and inorganic constituents – potentially leading to degraded groundwater quality.

4.2.2 Groundwater Quality

Potential effects of intentional recharge on groundwater quality must also be considered. Pollutants, like salts present, may be leached from the upper soil profile during infiltration. In addition, a rise in aquifer water levels due to the additional recharge may saturate portions of the upper soil profile allowing pollutants to be dissolved and the water quality degraded. Conversely, in some cases the increased recharge due the project may have a beneficial impact by diluting degraded water quality in a depleted aquifer.

4.3 Economics

After conjunctive management project goals and potential elements to meet those goals have been defined, economic factors are often used by stakeholders as a metric for comparing alternatives. Sections 4.3.1 and 4.3.2 described some of these economic factors.

4.3.1 Economic Benefits

Economic benefits of a conjunctive management project, unlike the water yield increase, typically cannot be directly measured. Methods for evaluating the economic benefits of a project could include:

- Estimating a value for the net water yield of the project (dollars/acre-ft) based on demand or
- Comparison of project costs to alternative projects capable of producing equivalent quantity and quality of water or
- Estimating value of increased production due to net yield (hydropower generated, crop production increases, recreational benefits).

In some instances the economic benefits are more difficult to quantify, such as a project's direct and indirect contributions to the overall economic viability of the area.

4.3.2 Economic Costs

Unless funding sources require a full Benefit:Cost Evaluation, a Partial Budgeting Approach (PBA), may be the best way to describe the costs of the project. This PBA method evaluates those costs which change with the implementation of the project without requiring the calculation of costs which do not change. Different entities will be concerned with different types of costs and changes. Those who fund the project, whether it be the State, NRD or Irrigation District, will be interested in the Capital Costs, Operation and Maintenance Costs, and Mitigation Costs. The land owners and operators will want to know about Replacement Pumping Costs, Other Production Costs, and Potential Changes in Output. Local businesses and government will ask for the impacts on the local Real Estate Tax Base, changes in Infrastructure that might be needed, and Rollover Economic Impacts for the region.

4.3.2.1 Capital Costs

Capital costs to consider generally consist of land required for the recharge facilities and the construction and material costs for the facility itself, consisting of diversion, conveyance, and recharge basin(s) elements. Numerous sources of cost data for estimation purposes are readily available, including:

- Bid tabulations from recent projects involving similar elements,
- Bid tabulations or cost information from other agencies, such as Nebraska Department of Roads and NRCS,
- Discussions with local contractors,
- Recent estimates on similar projects in the area,
- Recent land transaction data, and
- Manufacturer quotes.

4.3.2.2 Operation and Maintenance Costs

Operation and maintenance (O&M) costs of the proposed project will generally increase over current operations due to the additional facilities and extended diversion season. Estimates of O&M costs can be developed based on extrapolation of historic O&M costs of the current facility to the proposed facility and anticipated operation. Another approach to estimating O&M costs commonly employed is based on a percentage of the facility capital costs. Guidance on appropriate percentages can be found in a variety of sources, including American Society of Civil Engineer cost estimating guidance, and Nebraska Natural Resources Development Fund (NRDF) guidelines.

4.3.2.3 Mitigation Costs

Any negative impacts on third party groups or the environment in general may require some sort of mitigation in order to replace any losses they may have suffered. Nebraska Game and Parks Commission and US Fish and Wildlife Service may be able to provide guidelines or estimated costs based on past projects.

4.3.2.4 Production Costs (Replacement Pumping Costs)

For groundwater recharge projects that include replacement pumping to balance the lost surface water deliveries, production costs may be increased due to increased operation of groundwater wells and the additional costs associated with lifting water to the surface for use. The University of Nebraska – Institute of Agricultural and Natural Resources has several publications that can be used to estimate replacement pumping costs.[6]

4.3.2.5 Other Production Costs

Any changes in irrigation availability may require the use of different seed varieties, and potential changes in the requirements for harvesting and drying of grain or goods produced.

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[6] University of Nebraska-Lincoln - Agricultural Economics Department, *Cornhusker Economics*, “Irrigation Pumping Costs”, Selley, R, 2001.

4.3.2.6 Potential Changes in Output

For groundwater recharge projects that preclude surface water deliveries without replacement pumping to balance the lost surface water deliveries, users may see a decrease in production. The lost revenue may be estimated based on units of production (bushels of grain or lbs of beef) and current value of that production.

4.3.2.7 Real Estate Tax Base

Changes in water availability can have an impact on the value of land. If a project results in a reduced risk of not having irrigation water, that land gains in value and may potentially add to the tax base. Any changes that would increase the risk of not having irrigation water could reduce the local tax base.

4.3.2.8 Infrastructure

Any project of such as size as to increase the local population, require better roads, change the rate of crime in an area, etc., will introduce additional costs to local governments and service providers. Small projects may require no changes.

4.3.2.9 Rollover Economic Impacts

In some instances the initial economic impacts are multiplied in a region. Input/output (I/O) models , such as the IMPLAN model[7], are the standard tools for estimating the direct and indirect effects on the overall economic viability of the area. I/O models create a an accounting framework for a regional economy which describing flows of outputs to and from industries and institutions. In the models, economics sectors can: purchase outputs of other sectors, sell to other sectors, sell outside the local economy, and buy outside the local economy. This accounting framework allows the user to predict how a change in the level of economic activity will affect the local economy.

4.4 Environmental Considerations

Table 2 summarizes a sampling of environmental considerations for conjunctive management projects that must be considered and should not be considered exhaustive. Each project will likely be unique in the environmental considerations.

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[7] IMPLAN is a proprietary model developed by the Minnesota Implan Group Inc. (MIG). Software and Datasets available from www.implan.com

Table 2: Environmental Considerations Summary

Environmental Considerations	Potential Negative Impacts	Potential Positive Impacts
Physical Impacts of Facilities	Losses of existing scenic, recreation, fishery, wildlife riparian habitat value	Increased ecological function, quantity and quality of habitat, recreation and aesthetic amenities
Effects of Water Application	Erosion, gullying, salinization of soils, pollutant mobilization	Enhance ability of crops to utilize nutrients, reducing residual pollutants
Groundwater Pumping Effects	Land subsidence, intrusion of poorer water quality, drying of marshy habitats	Management of historically high groundwater tables
Energy Consumption and Generation	Increase in energy consumption for pumping (supplemental, injection, or recovery)	Increased hydropower generation, reduction in pumping depths, potential reduction in pumping
Health and Social Aspects	Potential of groundwater contamination, propagation of mosquitoes, impacts to cultural resources	Reduction in risk of economic and environmental impacts of prolonged drought, flood reduction
Land and Vegetation	Erosion, phreatophyte intrusion, limit future land uses, saturation of low lying areas	Riparian vegetation around perimeter of facilities

5.0 Legal Constraints

5.1 Current Water Law

Surface water in the State of Nebraska is administered by the Department of Natural Resources based upon the prior appropriation system established in the state constitution and state statutes. Permits or appropriations are granted by the Department which establish the date of the water right among other attributes.

Surface water appropriations can be divided between those for natural flow uses and those for the storage of water. Natural flow appropriations can be for irrigation, industrial, domestic, municipal induced recharge, hydropower, incidental recharge and instream flow. Storage can be for above ground storage or an intentional underground storage project. To use storage water, an entity or individual must obtain an appropriation from the Department and must provide the Department with a copy of a contract between the entity that stored the water and the user showing the right to use the water has been authorized by the entity that was granted the appropriation to store the water. Water rights for use of natural flow and for storage of natural flow are administered pursuant to the prior appropriation system. Use of stored water is administered pursuant to the contract for use and the storage use rights granted by the Department.

To obtain an appropriation an applicant must demonstrate that unappropriated water is available. If the application would be from a source in an area that has been declared to be fully or over-appropriated and thus is subject to a moratorium on the issuance of new water rights, then it would be necessary to file a petition to demonstrate good cause for a variance from the moratorium. Additionally the applicant must identify the location of diversion, the place of use, and the facilities associated with the appropriation. A map has to be provided for many uses reflecting the area covered by the appropriation.

In addition to obtaining a new appropriation, a project sponsor could also seek to transfer all or a portion of an existing water right to an intentional groundwater storage project. In this instance it would be necessary to comply with the statutes governing a transfer. As an aspect of the transfer it would be necessary to demonstrate no harm to existing users.

Hypothetically an entity could seek a new appropriation for replacement or recharge of groundwater. In such an instance "ownership" of the right to use the diverted surface water would be extinguished upon its recharge of depleted groundwater. This use would be for the purpose of recharging groundwater that had been previously withdrawn and used. It would be in contrast to the intentional storage of surface water for the purpose of later withdrawal of stored underground water. In this latter instance the water stored underground would still be subject to use by the entity that placed the water underground and could enter into contracts for the use of the water.

5.2 Legal Obligations of Participants

Legal instruments are required to define the roles and responsibilities of the project stakeholders and participants. Project elements ranging from ownership of infrastructure and recharge water to operation and maintenance responsibilities must be agreed upon by project stakeholders and contractual obligations defined. Other potential legal issues to be addressed include:

- What are legal rights of 'third-parties' to extract and use recharge water? How will this be enforced? Who is responsible for enforcement?
- Who is legally responsible for groundwater quality modification impacted by artificial recharge?
- What is legal liability associated with any increased costs to water rights holders?
- What is legal liability associated with any infrastructure impacted by changes in groundwater table elevations due to a conjunctive management project?

5.3 Permitting

In addition to submitting a petition showing good cause for a variance from any moratorium, an applicant would also need to apply for and secure the necessary water right permits from the state based upon the design and operation of the project. Additionally if a dam is included then the safety of dams statutes would need to be consulted to assure that any obligations created by them are met.

In relation to federal laws, the US Army Corps of Engineers under Section 404 of the Clean Water Act has been delegated regulatory responsibility regarding the issuance of permits related to waters of the Untied States. Thus to the extent that the statutes or rules and regulations pertaining to that Act require permits it would be necessary for participants to comply with those requirements.

Groundwater recharge projects often involve sites where streams, wetlands and other jurisdictional waters of the United States are prevalent and may be impacted. These potential direct (fill placement, etc.) and indirect (change in hydrologic regime, etc.) impacts to jurisdictional waters of the United States must be identified and quantified. Avoidance and minimization alternatives will require investigation and will generally be required as part of the United States Army Corps of Engineers (USACE) Section 404[8] permitting process. The Nebraska Department of Environmental Quality (NDEQ) is also involved in the Section 404 process as the regulatory authority responsible for issuing water quality certification that the project is compliant with Section 401 of the Clean Water Act. Early coordination with these regulatory agencies during project development is recommended to clearly understand permit issues and requirements while the flexibility to address these issues still exists.

Beyond the construction impact to waters of the United States addressed under Section 401, NDEQ also has several permit requirements that may relate to conjunctive management projects.[9] Depending on the source of the recharge water (treated wastewater effluent, for example), use of a recharge pit may require a construction permit from the Wastewater Section. Recharge using injection wells does require a permit from NDEQ and requires that the recharge water meets drinking water standards. Active management of return flows through pumping water to a receiving stream may require a National Pollutant Discharge Elimination System (NPDES) permit that could stipulate quantity and quality standards for return flows depending on the characteristics of the receiving stream, and if that water is to be protected would require a conduct water permit from NDNR. Local NRDs would require a groundwater well construction permit and possibly a transfer permit or other variance depending on the situation.

Finally, local jurisdictional authorities may have permit requirements standard for site development types of projects. These could include floodplain development permits, building permits, right-of-way agreements with public and private infrastructure interests, and other local ordinances.

6.0 Project Monitoring

As part of the development of a conjunctive management project, a monitoring plan should be developed for assessing project performance following completion and initiation of operations. At a minimum, this monitoring plan should include:

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[8] Section 404 of the Clean Water Act

[9] Personal communication with NDEQ, March 2011

- Installation of monitoring wells to allow recording of groundwater elevation fluctuations and collection of samples for groundwater quality analyses
- Installation of a surface water gaging station near the downstream extent of the anticipated project impacts to record flow rates and volumes, as well as samples for surface water quality analyses
- Monitoring of seepage rates of intentional recharge facilities to determine initial seepage rates and monitor declines in those rates that will define maintenance schedules
- A soil sampling and testing plan to monitor potential changes in soil chemistry

7.0 Western Canal Case Study

As part of the development of this conceptual design for groundwater recharge projects, the Western Canal was selected as a case study to develop a hypothetical project and illustrate the components for developing and evaluating groundwater recharge projects. The objectives of this case study were to develop a variety of groundwater recharge alternatives, identify and assemble necessary data for conducting the analysis, and perform an analysis of yield to the river for each groundwater recharge alternative.

The Western Irrigation District diverts South Platte River flows just downstream of the Julesburg gage. Delivery to producers is made via the 20-mile main canal that parallels the South Platte River south of Interstate 80, and its associated network of turnouts and laterals. The total irrigated acreage served by the Western Canal is 10,312 acres[10] under Appropriations A-393, A-1804, and A-4739. A location map of the Western Canal is illustrated in Figure 1. Hypothetical project goals include maximizing the available supply for the agricultural use of water to irrigate crops while maintaining or improving the stream flow on an annual timescale.

7.1 Data Collection

Available background data regarding the Western Canal project and surrounding area was compiled from a variety of sources, including the NDNR, Twin Platte Natural Resources District (TPNRD), Cooperative Hydrology Study (COHYST) reference materials, and the United States Geological Survey (USGS). A summary of pertinent information is provided herein.

7.1.1 Field Visit

A field visit to the Western Canal was conducted on April 13, 2010. Participants included NDNR staff, TPNRD staff, HDR, Inc. and The Flatwater Group (TFG) staff, and Western Canal representatives. Representatives from North Platte Natural Resources District (NPNRD), Central Platte Natural Resources District (CPNRD), USGS, Central Nebraska Public Power and Irrigation District (CNPPID), and Nebraska Public Power District (NPPD) were also present. Several potential recharge sites were identified prior to

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[10] From DNR Order, dated October 14, 1993

the field visit and annotated on work maps of the Western Canal area. These sites are annotated on Figure 1. Soils data at the potential recharge sites were assembled from NRCS soil survey data. Work maps and site soils information were provided to all attendees. Copies of the work maps, soil data and photographs from the field visit are included in Appendix A.

7.1.2 Existing Irrigation

The Western Irrigation District diverts South Platte River flows just downstream of Julesburg, Colorado. Approximately 10,312 acres are served by the canal, with a total appropriation of 176 cubic feet per second (cfs). The earliest priority date of the Western Canal appropriations is June 14, 1897. Based upon NDNR and NRD records as well as the field investigation, nearly all of the irrigated lands are currently co-mingled (surface and groundwater sources available) and are treated as fully co-mingled in this analysis. Most of the irrigated lands use center-pivot application methods.

7.1.3 Soils Data

Soils data in the project area was gathered from NRCS soil survey data and summarized in Appendix A. No additional field data collection or sampling was conducted as part of this case study. Generally, soil types are sandy loams with Bayard very fine sandy loam, Duroc loam, and Wann fine sandy loam, being the most prevalent. These soils are characterized as somewhat poorly drained to well drained, with Ksat[11] estimates ranging from 0.6 to 6 in/hr (1.2 to 12 feet/day).

7.1.4 Topography

A GIS topographic shape file in the project area was gathered from USGS 10-m digital elevation mapping. No additional topographic data was collected as part of this case study. The difference in elevation from the main canal elevation to the South Platte River channel varies from 30-foot at the upstream end to 70-foot at the downstream end. The topography shape file was used in conjunction with the groundwater elevation shape file[12] to estimate depth to the water table in assessing the feasibility of recharge sites.

7.1.5 Aquifer

The Ogallala aquifer underlies the Western Canal through the project area. Groundwater elevation data collected from monitoring wells by TPNRD[13] was used to develop a GIS shape file of groundwater contours. The groundwater contour elevation map is provided in Figure 1.

The SDF method was used to represent surface water/aquifer interaction in this case study. The SDF has a unit of days and is defined by Jenkins[14] as the area within which, from the time of pumping initiation, the stream depletion is 28% of the volume pumped. SDF values for the project area were taken from the

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[11] Capacity of the most limiting layer to transmit water

[12] Groundwater Elevation Data (2009) provided by Twin Platte Natural Resources District.

[13] Reference date needed

[14] Jenkins, C.T. Techniques for Computing Rate and Volume of Stream Depletion by Wells, USGS. 1967.

Platte River Level B Study[15] and an SDF contour plot provided in Figure 2. An SDF value of 1500 days will be used as representative of the project area based on interpolation of the SDF contours shown in Figure 2.

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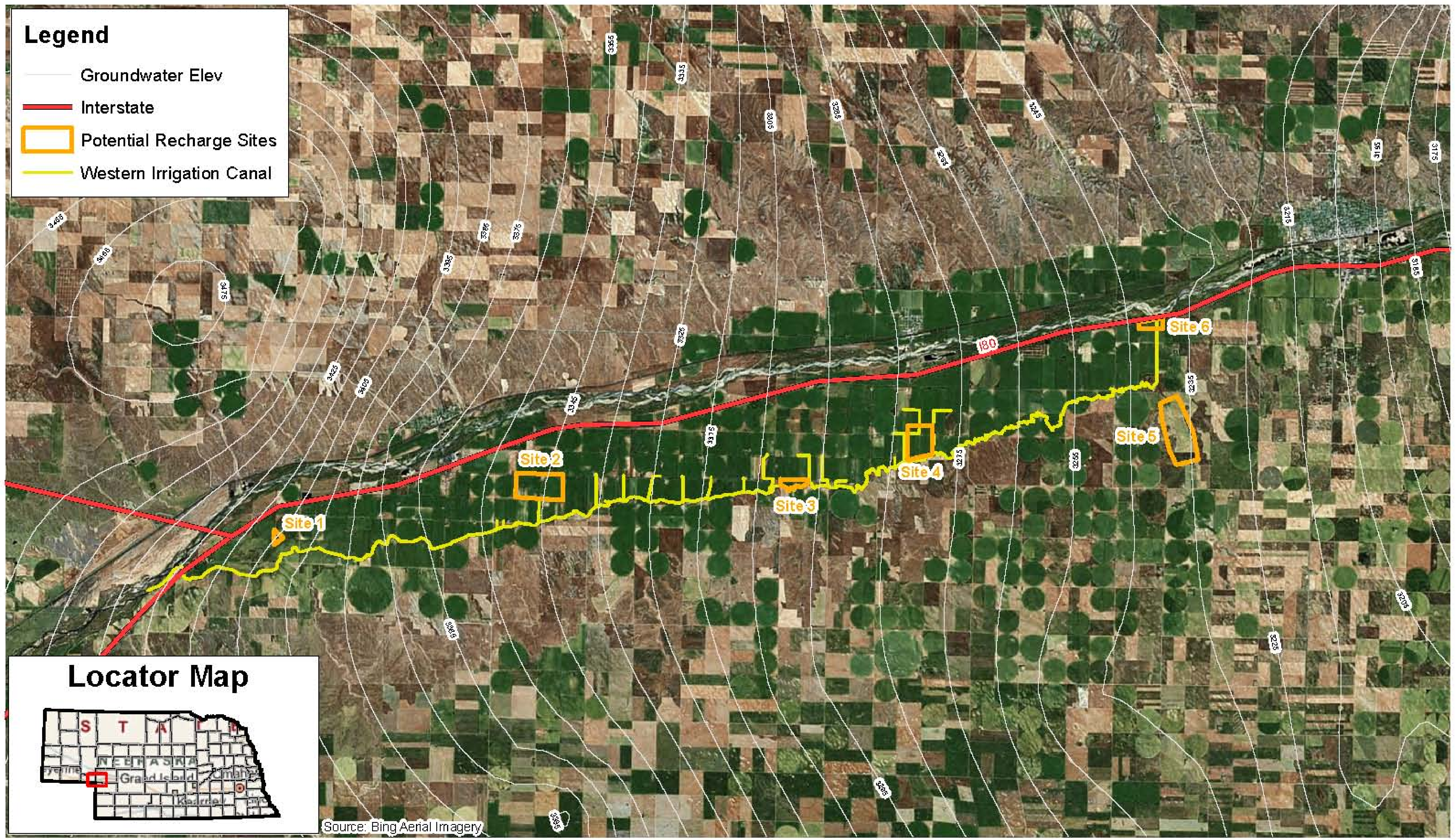
[15] Missouri River Basin Commission, Platte River Level B Study, 1976.



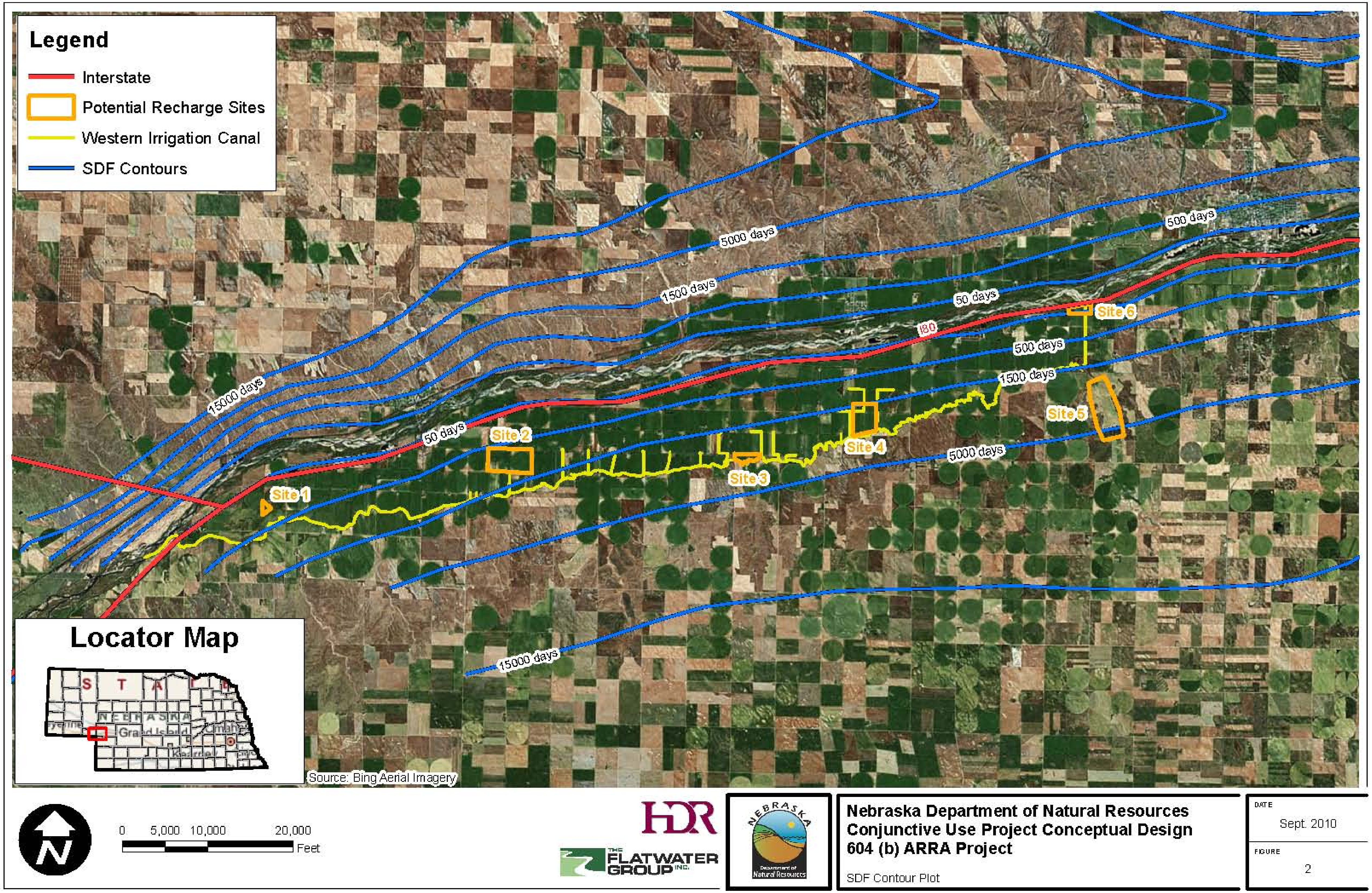
Source: Bing Aerial Imagery

Nebraska Department of Natural Resources
Conjunctive Use Project Conceptual Design
604 (b) ARRA Project

Groundwater Contour Plot

DATE
Sept. 2010

FIGURE
1



Nebraska Department of Natural Resources
Conjunctive Use Project Conceptual Design
604 (b) ARRA Project

SDF Contour Plot

DATE
Sept. 2010

FIGURE
2

7.1.6 Existing Infrastructure

Information on existing infrastructure that may be used or impacted by the groundwater recharge project alternatives was assembled. A summary of this information includes:

- Diversion capacity of existing head works is 250 cfs,
- An existing overhead power line is located near Site 6 that may limit expanding or enhancing the site,
- Numerous existing reuse pits were noted, largely in the one to five acre size range that could serve as recharge facilities,
- Parcels that use gravity/flood or no irrigation were identified so operation of center-pivots would not be disrupted by potential pits,
- Existing farmsteads and homes were located to avoid potential high groundwater table impacts, and
- The existing roadway network and field access was considered to prevent impacting parcel access.

7.2 Water Supply

Three water supply concepts were evaluated for the Western Canal groundwater recharge project. The first concept is based on historic flow records in the South Platte River. The second concept is based on the historic diversion record of Western Canal. The third concept is based on estimated excess to state protected flows available in the South Platte River at the Western Canal head gates based on a previous DNR study[16]. The period of record utilized to develop these water supply concepts was 1988 through November 1997, this period is representative of 'average' flow conditions and is used to estimate expected flows in the South Platte River[17].

7.2.1 Historic South Platte River Flows and Western Canal Appropriation

Historic South Platte River flows at the Western Canal head gate were determined by using the gage record for the South Platte River at Julesburg, Colorado (USGS Gage No. 6764000). The historic gage record was capped at 176 cfs, limiting the flows available for diversion to the Western Canal appropriation. The potential diversion by Western Canal was then determined as the lesser of the daily flow at the Julesburg gage or the Western Canal appropriation of 176 cfs. These daily flow values over the 1988-1997 period were aggregated to monthly flow volumes for the period. Table 3 summarizes the monthly potential diversion volumes.

An alternative method for determining water supply is to develop monthly flow duration curves (FDC) for each month. The FDC is useful in illustrating the probability of expected flows. When planning a

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[16] "Evaluation of Historic Platte River Streamflow in Excess of State Protected Flows and Target Flows". HDR and The Flatwater Group. 2010.

[17] Based on conversations with Nebraska DNR and Twin Platte NRD staff

potential groundwater recharge project, the desired certainty of water availability can then be used in conjunction with the FDC to determine expected water supplies for the project.

Table 3: Monthly Historic Flow Volumes at Julesburg Gage (Acre-Feet)

	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	**Monthly Average**
March	10545	10545	10803	10803	10803	10803	10803	8435	10803	10803	**10515**
April	10454	9066	10454	9750	10454	10454	8829	10387	9449	10159	**9946**
May	10753	2798	6732	6215	3186	7995	5194	10797	8090	6261	**6802**
June	9660	4706	5093	10118	9367	8401	3419	10454	10454	10454	**8213**
July	3918	1861	1818	3059	8758	2873	1558	10803	5124	7882	**4765**
August	3132	3216	4821	3615	8405	2903	1230	7712	5869	10803	**5171**
September	5619	9916	5714	8391	10454	8403	1241	8122	10454	9906	**7822**
October	7997	7453	9332	8659	10803	10803	8045	10803	10803	10803	**9550**
November	6395	4419	8726	6249	9571	10411	5019	10454	10153	10454	**8185**
Annual Total	**68476**	**53981**	**63493**	**66859**	**81802**	**73046**	**45338**	**87967**	**81200**	**87526**	

7.2.2 Western Canal Historical Diversion

The second water supply concept utilized the Western Canal historical diversion records from 1988 through 1997[18]. The daily diversions were converted to monthly diversion volumes. The monthly diversion volumes are provided in Table 4.

Table 4: Western Canal Historic Diversion Volumes (Acre-Feet)

	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	**Monthly Average**
March	-	-	-	-	-	-	-	-	-	-	**-**
April	-	-	246	-	--	-	1,392	-	2,043	-	**368**
May	847	3,027	4,546	4,528	2,206	263	3,802	-	2,043	-	**2,789**
June	4,441	3,792	3,970	5,063	5,540	3,126	2,792	887	3,507	6,435	**3,955**
July	6,207	2,449	2,992	4,617	6,281	3,447	1,851	7,015	5,320	7,633	**4,781**
August	3,582	4,562	5,263	4,110	8,389	3,493	1,321	6,053	5,425	8,132	**5,033**
September	3,619	4,441	4,235	4,538	8,207	3,711	921	6,085	1,938	6,287	**4,398**
October	3,794	1,188	3,368	2,271	3,459	2,437	3,285	1,142	-	1,873	**2,282**
November	2,330	-	1,968	-	537	91	-	-	-	-	**493**
Annual Total	**24,820**	**19,460**	**26,590**	**25,130**	**34,620**	**16,570**	**15,360**	**21,180**	**23,690**	**33,570**	

7.2.3 Excess to State Protected Flows at Western Canal Diversion

Excess to state protected flows were estimated from a previous NDNR study.[19]. The tool accounts for South Platte River inflows, existing downstream state protected flows and reach gain/losses that occur

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[18] From Nebraska DNR gage records

[19] "Evaluation of Historic Platte River Streamflow in Excess of State Protected Flows and Target Flows". HDR and The Flatwater Group. 2010.

through the system to estimate the available excess water potentially available for diversion under a new appropriation. Table 5 summarizes the estimated excess monthly flow volumes available for diversion.

Table 5: Western Canal Excess to State Protected Flow Monthly Volumes (Acre-Feet)

	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
March	-	248	-	-	-	1,452	-	-	-	-
April	-	-	-	-	--	-	-	-	-	-
May	984	-	-	-	-	-	-	11,342	-	-
June	-	-	-	-	-	-	-	526,707	-	203,097
July	-	-	-	-	-	-	-	117,122	-	1,567
August	-	-	-	-	-	-	-	-	-	21,638
September	-	-	-	-	-	-	-	-	7,549	262
October	-	-	-	-	-	-	-	-	2,926	1,291
November	-	-	-	-	-	-	-	-	-	811

7.3 Diversion Operations

Three concepts for operation of the Western Canal diversion were evaluated for this project. To fully illustrate the potential benefits of the groundwater recharge project, two of the concepts include extending the historic diversion season. It is recognized that there may be potential constraints on the existing appropriation that may limit the diversion season, but for the illustrative purposes of this example, such constraints are neglected. The first operational concept assumes a full diversion season from March 1 through November 30. The second operational concept assumes a full diversion season from April 1 through October 15. The third operational concept is based on the historic diversions for the 1988-1997 period. The average start and end dates for the historic operations of the canal during that period are May 13 and October 23.

7.4 Recharge Facilities

Three types of recharge facilities were considered: 1) the main canal of the Western Canal project; 2) existing reuse pits; and 3) intentional recharge pits.

7.4.1 Main Canal of Western Canal

The main canal of the Western Canal project is approximately 20 miles in length, with a typical wetted perimeter of 30 feet. The analysis conducted for the current Platte River Conjunctive Management Project[20] estimates the constant seepage rate of the main canal at approximately 60 cfs/day, or 3,700 acre-feet per month.

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[20] Current study effort of the COHYST Sponsor Group

7.4.2 Existing Reuse Pits

Many of the agricultural fields in the project area have existing reuse pits that historically have been used to collect irrigation runoff for the purpose of reuse. Many of the facilities also have the infrastructure in place to convey water from the reuse facility back to the turnout off the main canal that could be reversed to convey flows for recharge to the reuse pits. The area of the reuse pits typically vary from one to five acres in area.

7.4.3 Intentional Recharge Pits

Several potential locations for recharge pits were identified from desk top surveys and investigated during the site visit. The six sites identified are illustrated in Figure 1, and a summary of relevant information for each site is provided in Table 6.

Table 6: Intentional Recharge Facility Information

Site	Approximate Areas (acres)	Estimated Depth to Groundwater (ft)	SDF (days)	Notes
1	20	10	300	Existing reuse pit complex, standing water present during site visit, shallow groundwater table.
2	300	14	800	Area between irrigated parcels, building site located ½ mile to the northeast, relatively shallow groundwater.
3	40	70	3000	Irregular, narrow parcel located adjacent to main canal, between canal and county road.
4	200	40	2000	Parcel adjacent to main canal, existing laterals parallel both sides.
5	440	90	4500	Dry dam detention area. Site would require lift station to pump flows to basin.
6	40	10	50	Existing reuse pits immediately adjacent to Interstate 80 ROW, some standing water during site visit, shallow groundwater table, overhead electrical and I-80 ROW constraints.

Based on the existing constraints and characteristics, Sites 2, 3, and 4 appear to be the most feasible locations for a potential intentional recharge facility.

7.4.4 Estimated Recharge Rates

Typical infiltration rates for the Platte River valley are estimated at 1.0 to 3.0 feet/day depending on the level of silts and fines present in the soil matrix. Based on the prevalent soil types at the project site, an infiltration rate of 2.0 feet/day is used in the evaluation of Western Canal groundwater recharge project alternatives.

7.4.5 Required Size of Recharge Facilities

The areal extents of the recharge facilities are based on the recharge volume required. Based on the appropriations' maximum diversion rate of 176 cfs, the maximum monthly diversion volume is 10,820 acre-feet. Assuming the full main canal is available for recharge (monthly recharge volume of 3,700 acre-feet), 7,120 acre-feet is the required monthly recharge volume required of the recharge facilities. Using the assumed constant 2.0 feet/day infiltration rate, the required surface area of the recharge facilities is then 115 acres. Adjusting the required area by 20% to account for contingencies, the required area is then 140 acres. With an average reuse pit area of three acres, approximately 50 existing reuse pits would be required.

Based on the 140 acre size requirement, Sites 2 and 4 could each independently meet the facility requirements. Site 3, with its area limited to 40 acres, would need to be considered in conjunction with Site 2 and/or Site 4 to provide the necessary recharge capacity.

Historic gage records indicate the maximum recharge volume is likely to be available for only a few months of the year. It is anticipated that recharge facilities could be rotated throughout the remainder of the year as required for maintenance, etc., such that redundancy in recharge facilities will not be required. Likewise, because of the variability in recharge volume throughout the year, it is recommended that recharge cell sizes be limited to 40 acres to allow operational flexibility.

7.5 Management of Return Flows

Passive management of return flows, consisting of natural groundwater return flows to the river, was used in the evaluation of the Western Canal groundwater recharge project alternatives. Passive management was selected based on current TPNRD goals of the potential project and the focus on offsetting annual depletions to 1997 levels. Because of the annual timescale, active management of return flows (surface or groundwater wells) to meet seasonal or short duration target flows is not necessary, and therefore was not included in this analysis.

7.6 Net Yield Approach

The computation of net yield for this hypothetical groundwater recharge project requires the estimation of five quantities:

1) Computed recharge returns to the river of the proposed project;
2) Computed returns/spills to the river of the proposed project;
3) Computed depletions to the river based on additional pumping to replace lost surface water supply for irrigation;
4) Computed baseline recharge returns to the river based on historic operations of the canal system; and
5) Computed baseline returns and spills to the river based on historic operations of the canal system.

Combined, the following equation applies:

Net Yield to the River =
(Recharge returns of Proposed Project) + (Returns/Spills of Proposed Project)
– (Depletion of Replacement Pumping) – (Baseline Recharge Returns) – (Baseline Returns/Spills)

The baseline recharge return and baseline returns/spills volume will be the same for all potential groundwater recharge project alternatives investigated. Similarly the depletions due to replacement pumping will be the same for all potential groundwater recharge project alternatives that preclude delivery of surface water supplies to producers during the irrigation season. For potential groundwater recharge project alternatives that will deliver surface water supplies during the irrigation season, there would be no replacement pumping required and therefore no additional depletions.

The recharge returns and returns/spills of the potential groundwater recharge project alternatives will be unique to each project and depend on assumed surface water supply and pattern of diversion.

7.6.1 Baseline Recharge Returns and Baseline Returns/Spills

The baseline recharge return of the Western Canal system based on historic operations was estimated as follows:

1. The average monthly diversion volumes were computed using the 1988-1997 historic diversion volumes, as shown in Table 7.

Table 7: Western Canal Historic Diversion Volumes (Acre-Feet)

	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	**Monthly Average**
March	-	-	-	-	-	-	-	-	-	-	**-**
April	-	-	246	-	--	-	1,392	-	2,043	-	**368**
May	847	3,027	4,546	4,528	2,206	263	3,802	-	2,043	-	**2,789**
June	4,441	3,792	3,970	5,063	5,540	3,126	2,792	887	3,507	6,435	**3,955**
July	6,207	2,449	2,992	4,617	6,281	3,447	1,851	7,015	5,320	7,633	**4,781**
August	3,582	4,562	5,263	4,110	8,389	3,493	1,321	6,053	5,425	8,132	**5,033**
September	3,619	4,441	4,235	4,538	8,207	3,711	921	6,085	1,938	6,287	**4,398**
October	3,794	1,188	3,368	2,271	3,459	2,437	3,285	1,142	-	1,873	**2,282**
November	2,330	-	1,968	-	537	91	-	-	-	-	**493**
Annual Total	**24,820**	**19,460**	**26,590**	**25,130**	**34,620**	**16,570**	**15,360**	**21,180**	**23,690**	**33,570**	

2. The average diversion volumes in the non-irrigation season (pre-June 15 and post-August 31) were then adjusted for estimated evaporation/ET losses and spills or canal returns. Evaporation/ET losses were estimated at 3% of diversion and returns were estimated at 10% of diversion[21]. Applying these losses to the volume of diversion during the non irrigation season yields the non-irrigation volume of recharge illustrated in Table 8.

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[21] Evaporation/ET losses and return % estimates based on synoptic studies of Platte River canals conducted by NPPD, DNR, and CPNRD

Table 8: Western Canal Estimated Non-Irrigation Season Baseline Recharge and Return/Spills Volume (Acre-Feet)

	March	April	May	June	July	August	Sept	Oct	Nov
Average Diversion	-	368	2789	3955	4781	5033	4398	2282	493
3% Evap/ET	-	11	84	59	-	-	132	68	15
10% Returns/Spills	-	37	279	198	-	-	440	228	49
Recharge (Adjusted by 13% for losses)	-	320	2426	1721	-	-	3826	1985	429

3. The average diversion volumes in the irrigation season (June 15 – August 31) were then adjusted for estimated field deliveries, as well as evaporation/ET losses and spills or canal returns. Field deliveries were estimated as 50% of diversions. Evaporation/ET losses were estimated at 3% of diversion and returns were estimated at 10% of diversion, the same as non-irrigation season. Applying these losses to the volume of diversion during the irrigation season yields the irrigation volume of recharge illustrated in Table 9.

Table 9: Western Canal Estimated Irrigation Season Baseline Recharge and Returns/Spills Volume (Acre-Feet)

	March	April	May	June	July	August	Sept	Oct	Nov
Average Diversion	-	368	2789	3955	4781	5033	4398	2282	493
50% Delivery	-	-	-	989	2391	2517			
3% Evap/ET	-	-	-	59	143	151	-	-	-
10% Returns/Spills	-	-	-	198	478	503	-	-	-
Recharge (Adjusted by 63% deliveries and losses)	-	-	-	732	1769	1862			

4. The non-irrigation and irrigation season recharge volumes are then summed to yield the baseline monthly average recharge volumes as illustrated in Table 10.

Table 10: Western Canal Estimated Average Baseline Recharge and Return/Spills Volume (Acre-Feet)

	March	April	May	June	July	August	Sept	Oct	Nov
Average Diversion	-	368	2789	3955	4781	5033	4398	2282	493
Non-Irrigation Season Recharge	-	320	2426	1721	-	-	3826	1985	429
Irrigation Season Recharge	-	-	-	732	1769	1862	-	-	-
Average Baseline Recharge		**320**	**2426**	**2453**	**1769**	**1862**	**3826**	**1985**	**429**
Non-Irrigation Season Return/Spills	-	37	279	198	-	-	440	228	49
Irrigation Season Return/Spills	-	-	-	198	478	503	-	-	-
Average Baseline Returns/Spills	**-**	**37**	**279**	**396**	**478**	**503**	**440**	**228**	**49**

5. The baseline recharge return volumes to the river were then estimated using the average monthly recharge volumes computed in Step 4 and the SDF of 1500 days found in the Western Canal project area. The baseline recharge return flow hydrographs is predicted using Alluvial Water Accounting System (AWAS)[22]. The annual average recharge volume and the annual estimated baseline recharge returns to the river are illustrated in Figure 2.

   In addition to the 116 years of historic operation illustrated in Figure 2, the projected recharge return over the next twenty years due to historic operations (without further recharge occurring) is also illustrated in Figure 2. This future recharge return due to historic operations is noted here because in the computation of the groundwater recharge project net yields, the proposed project is assumed to begin at time zero. The 'tail' portion of the baseline recharge return due to historic operations illustrated in Figure 2 is not represented in the net yield computations of the potential projects, resulting in negative net yield values for the initial years of the proposed project. The negative net yield portion of the curve is illustrated in this report for completeness, however it should be recognized that this is a product of the computational methods and assumptions employed and described herein. The proposed projects will not result in negative net yields to the river.

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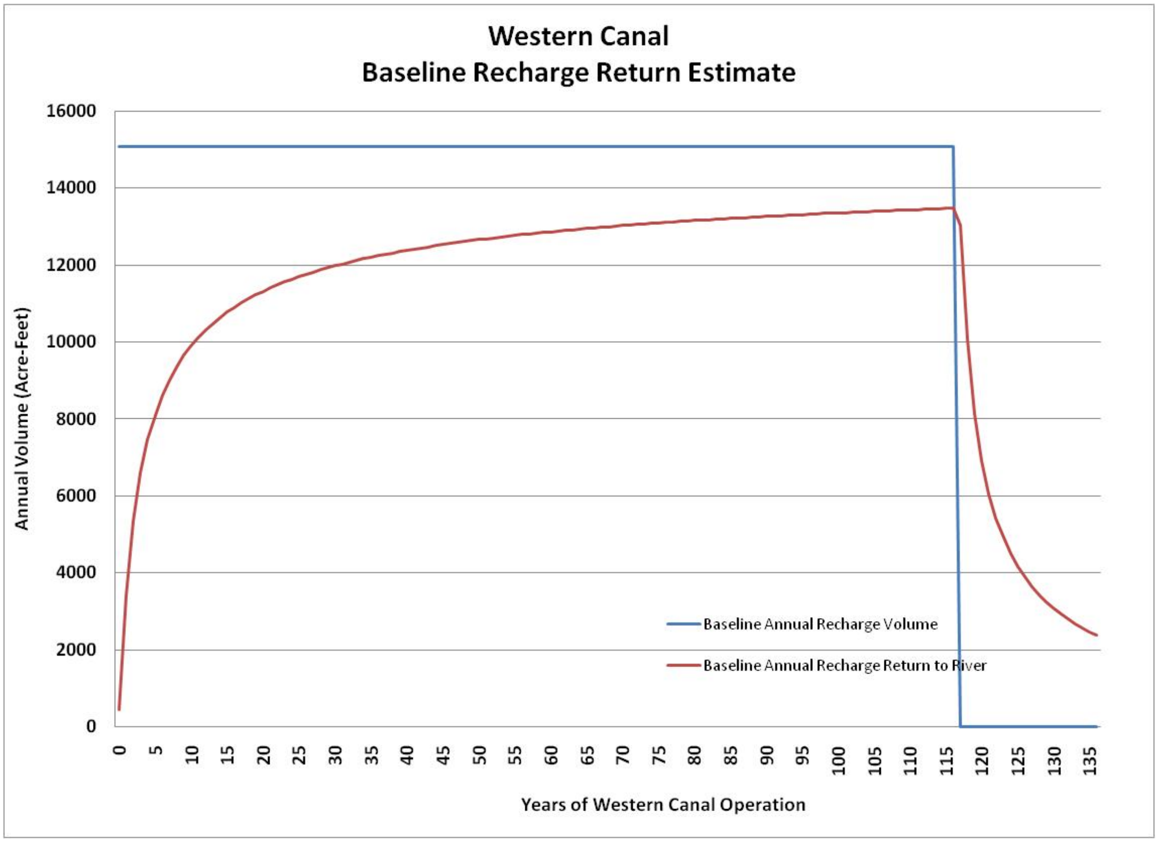
[22] AWAS is a modeling tool developed by the Integrated Decision Support Group at Colorado State University. AWAS can calculate river depletions using the Stream Depletion Factor method (Jenkins, 1968) or the The Analytical Stream Depletion method developed in 1987 by Dewayne R. Schroeder. The latter method uses analytical equations described by Glover (Glover, 1977) and others.

Figure 2 – Estimated Baseline Recharge Returns



Using the Western Canal operational history dating back a period of 116 years to 1894 and the asymptotic portions of the curve illustrated in Figure 2, a constant baseline recharge return of 13,500 acre-feet will be used in the net yield computations for the groundwater recharge project alternatives.

7.6.2 Depletions Due to Replacement Pumping

For some of the conceptual groundwater recharge project operations, it is assumed lost surface water supplies for irrigation will be replaced by additional groundwater pumping to meet the crop irrigation demands. This additional pumping, or replacement pumping as referred to in this document, will cause depletions to the river. These depletions must be accounted for in estimating the net yields of groundwater recharge projects that no longer deliver surface water to producers during the irrigation season. Consistent with the baseline recharge return estimation, the irrigation season was assumed to be June 15 – August 31 in this analysis. Depletions due to replacement pumping were then estimated as follows:

1. The average monthly diversion volumes during the irrigation season were computed using the 1988-1997 historic diversion volumes, as shown in Table 11.

Table 11: Western Canal Average Irrigation Season Diversion Volume (Acre-Feet)

	Average Diversion Volume (acre-feet)
June (15-30)	1978
July	4781
August	5033

2. Consistent with the baseline recharge return estimation, 50% of diverted flows during the irrigation season are assumed to be delivered to the field. The applied surface water is then as illustrated in Table 12.

Table 12: Western Canal Estimated Average Applied Surface Water Volume (Acre-Feet)

	Average Diversion Volume (acre-feet)	Average Applied Surface Water Volume (acre-feet)
June (15-30)	1978	989
July	4781	2391
August	5033	2517

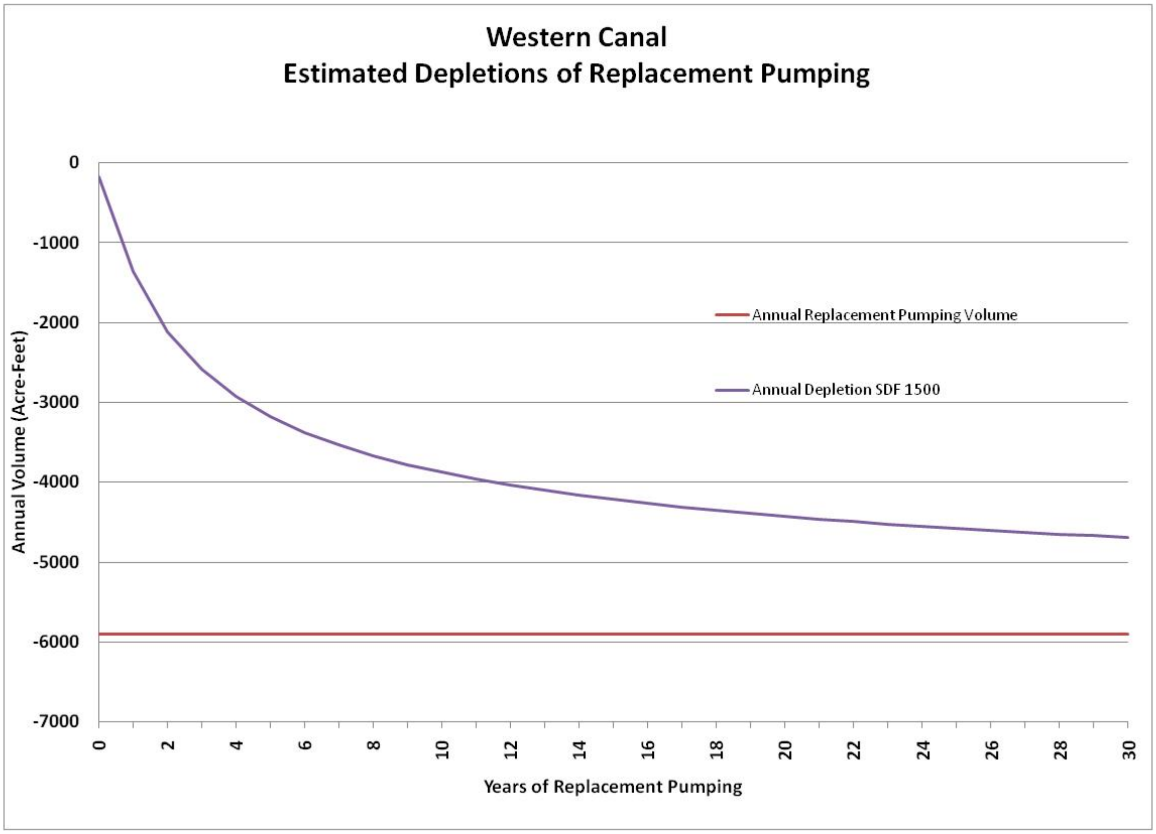
3. The delivery efficiency of the replacement pumping is estimated as 100%. Using this delivery efficiency, the required replacement pumping is then equal to the average applied surface water volume as illustrated in Table 13.

Table 13: Western Canal Estimated Average Required Replacement Pumping Volume (Acre-Feet)

	Average Diversion Volume (acre-feet)	Average Applied Surface Water Volume (acre-feet)	Average Required Replacement Pumping Volume (acre-feet)
June (15-30)	1978	989	989
July	4781	2391	2391
August	5033	2517	2517

4. Depletions to the river were then estimated over a 30-year period using the average required replacement pumping volumes computed in Step 3 and the average SDF of 1500 days found in the Western Canal project area. The AWAS modeling tool was again used for this analysis. The annual average replacement pumping volume and annual estimated depletions to the river are illustrated in Figure 3.

Figure 3 – Estimated Depletions from Replacement Pumping



7.7 Groundwater Recharge Project Alternatives

Several variations of water supply and diversion operation concepts were employed to develop potential groundwater recharge project alternatives. Table 14 defines the key components of the alternatives. Each alternative is discussed in more detail in subsequent sections.

Table 14: Western Canal Groundwater Recharge Project Alternatives

Alternative Name	Water Supply Concept*	Diversion Operations Concept**	Replacement Pumping?	Notes
1	Historic Diversion	Actual Historic Dates	Y	System operated solely as a recharge facility
2	Historic Diversions and Excess to State Protected Flows	March 1 – November 30	NA	Assumes new appropriation, normal Western operations, diversions limited to excess of historical diversion up to capacity
3a	Excess to State Protected Flows	March 1 – November 30	NA	Assumes new appropriation, normal Western operations, looks at 50, 100, 150, and 200 cfs diversion capacities
3b	Excess to State Protected Flows	April 1 – October 15	NA	Assumes new appropriation, normal Western operations, looks at 50, 100, 150, and 200 cfs diversion capacities
4a	Historic S. Platte Flow	March 1 –November 30	Y	System operated solely as a recharge facility
4b	Historic S. Platte Flow	April 1 – October 15	Y	System operated solely as a recharge facility
4c	Historic S. Platte Flow	May 13 – October 23	Y	System operated solely as a recharge facility
5a	Historic Diversions June 15-Aug. 31; Historic S. Platte Flow March–June 15, Sept. 1–Nov. 30	March 1 – November 30	Y	System operated solely as a recharge facility
5b	Historic Diversion June 15-Aug. 31; Historic S. Platte Flow April – June 15, Sept. 1 – October 15	April 1 – October 15	Y	System operated solely as a recharge facility
6a	Historic Diversions June 15-Aug. 31; Historic S. Platte Flow March–June 15, Sept. 1–Nov. 30	March 1 – November 30	N	Non-irrigation operation as a recharge facility, normal deliveries during irrigation season
6b	Historic Diversions June 15-Aug. 31; Historic S. Platte Flow April–June 15, Sept. 1–Oct. 15	April 1 – October 15	N	Non-irrigation operation as a recharge facility, normal deliveries during irrigation season

* Water supply concepts discussed in Section 7.2

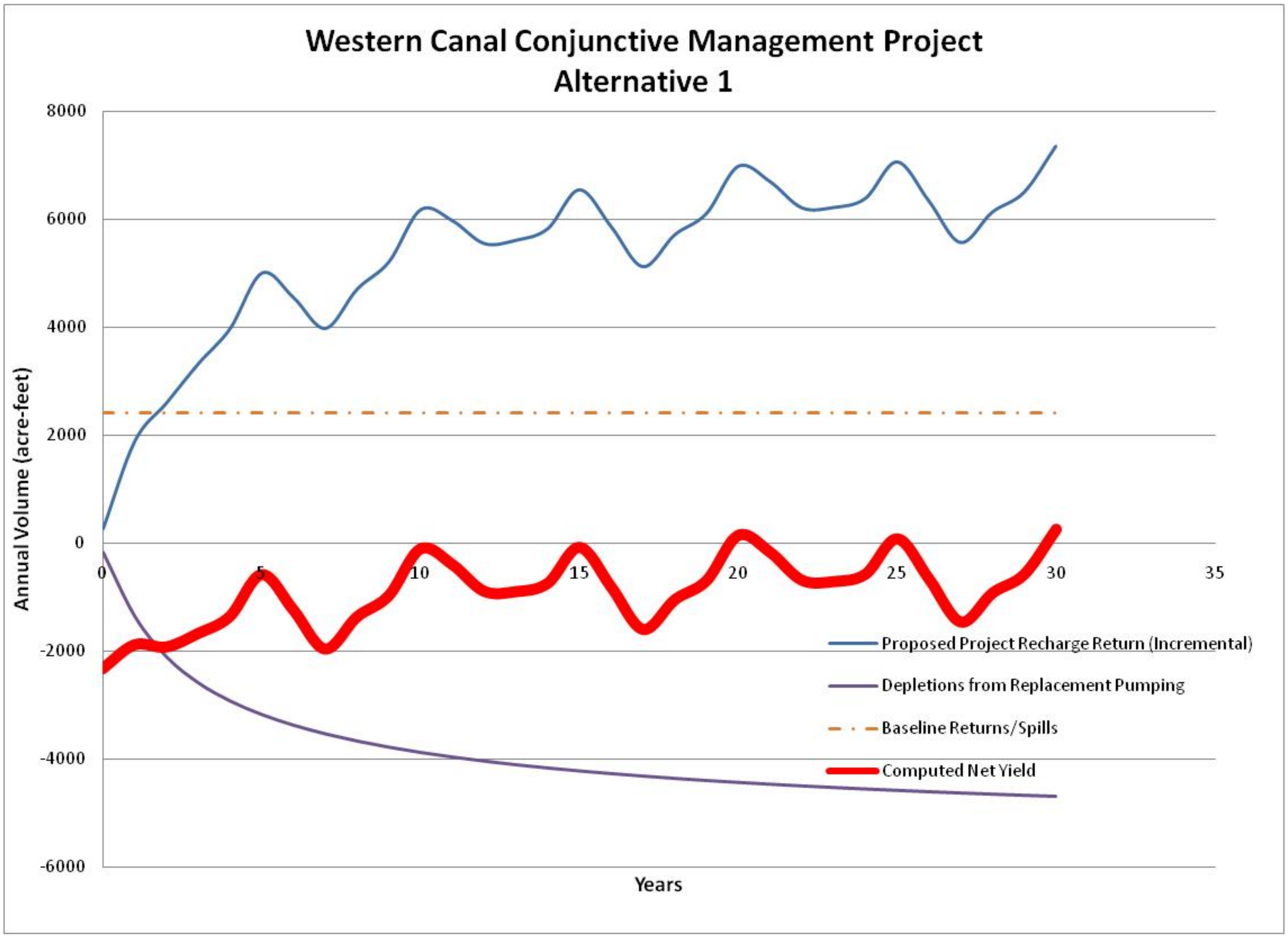
**Diversion operation concepts discussed in Section 7.3

7.7.1 Alternative 1

Alternative 1 assumes operation of the facility for recharge only, i.e. no surface water deliveries to producers for irrigation. The monthly recharge volumes used in this alternative are the incremental recharge volumes due to the new operational scenario, namely the 10% of spills under current operations and the volumes of surface water delivered to producers, estimated as 50% of the diversions June 15 through August 31.

These monthly incremental recharge values were then modeled over a 30-year period using the AWAS program and an SDF value of 1500 days to estimate the annual recharge return. Figure 4 illustrates the annual incremental recharge volume, annual depletion due to replacement pumping, annual baseline return/spills, and finally the annual net yield of the project.

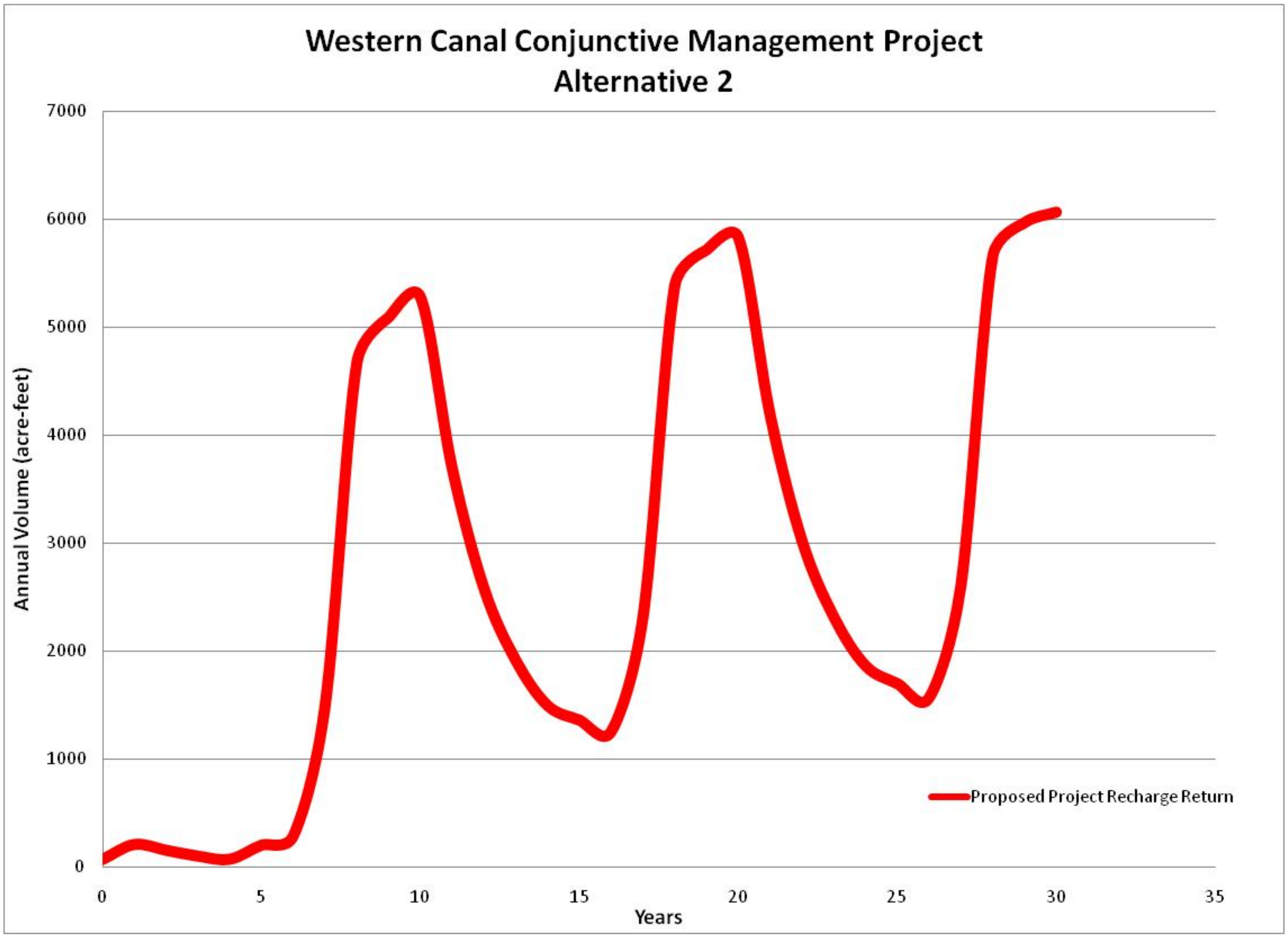
Figure 4 – Western Canal Alternative 1 Net Yield



7.7.2 Alternative 2

Alternative 2 assumes normal historic operations of Western Canal, with a new appropriation that could utilize the existing diversion and facility to capture excess to state protected flows for the purpose of recharge. The available water supply is based on the excess to state protected flows evaluation recently completed for DNR and described in Section 7.2.4. Potential diversions of excess flows were assumed to occur from March through November. The computed monthly volume of excess flow diversion was limited to the remaining diversion capacity available at the Western Canal Diversion under normal historic operations. The monthly excess flow volume diverted was adjusted to account for 5% losses to evaporation/ET to compute the incremental monthly recharge volumes (assumes 0% spills) due to capturing the excess flows. The monthly recharge for each diversion capacity was then modeled over a 30-year period (repeating the 1988-1997 data) using the AWAS program and an SDF value of 1500 days to estimate the incremental annual recharge return. Because this scenario represents a new use and new appropriation and Western Canal operations are assumed to continue under normal operations, the yield to the river is not adjusted for replacement pumping, baseline recharge returns, baseline returns/spills to the river. Figure 5 illustrates the annual incremental yield to the river estimates for Alternative 2.

Figure 5 – Western Canal Alternative 2 Net Yield



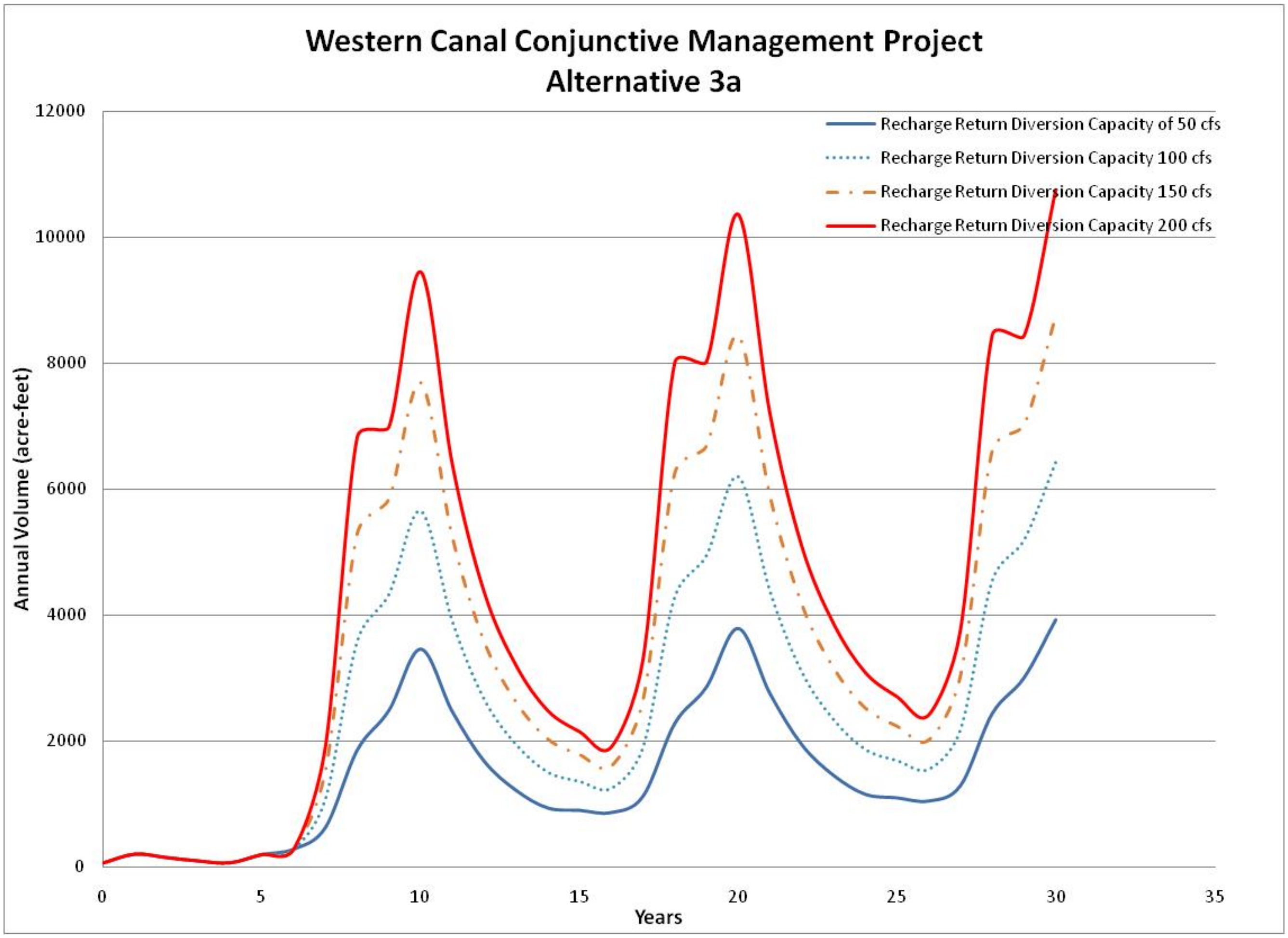
7.7.3 Alternative 3a

Alternative 3a assumes a new appropriation that could utilize the existing diversion and facility, or include a new diversion and facility for the sole purpose of recharge. The available water supply is based on the excess to state protected flows evaluation recently completed for NDNR and described in Section 7.2.4. Diversions were assumed to occur from March through November. The actual computed monthly volumes of excess to state protected flows for the period 1988 -1997 were adjusted to account for 5%

losses to evaporation/ET to compute the monthly recharge volumes (assumes 0% spills). The volume of water diverted is based on the maximum diversion capacity. To represent a range of potential diversion and facility options, four maximum diversion capacity scenarios were investigated: 50 cfs, 100 cfs, 150 cfs, and 200 cfs.

The monthly recharge for each diversion capacity was then modeled over a 30-year period (repeating the 1988-1997 data) using the AWAS program and an SDF value of 1500 days to estimate the annual recharge return. Because this scenario represents a new use and new appropriation, while the existing use continues as normal, the yield to the river is not adjusted for replacement pumping, baseline recharge returns, baseline returns/spills to the river. Figure 6 illustrates the annual yield to the river estimates for the four diversion capacity scenarios.

Figure 6 – Western Canal Alternative 3a Net Yield



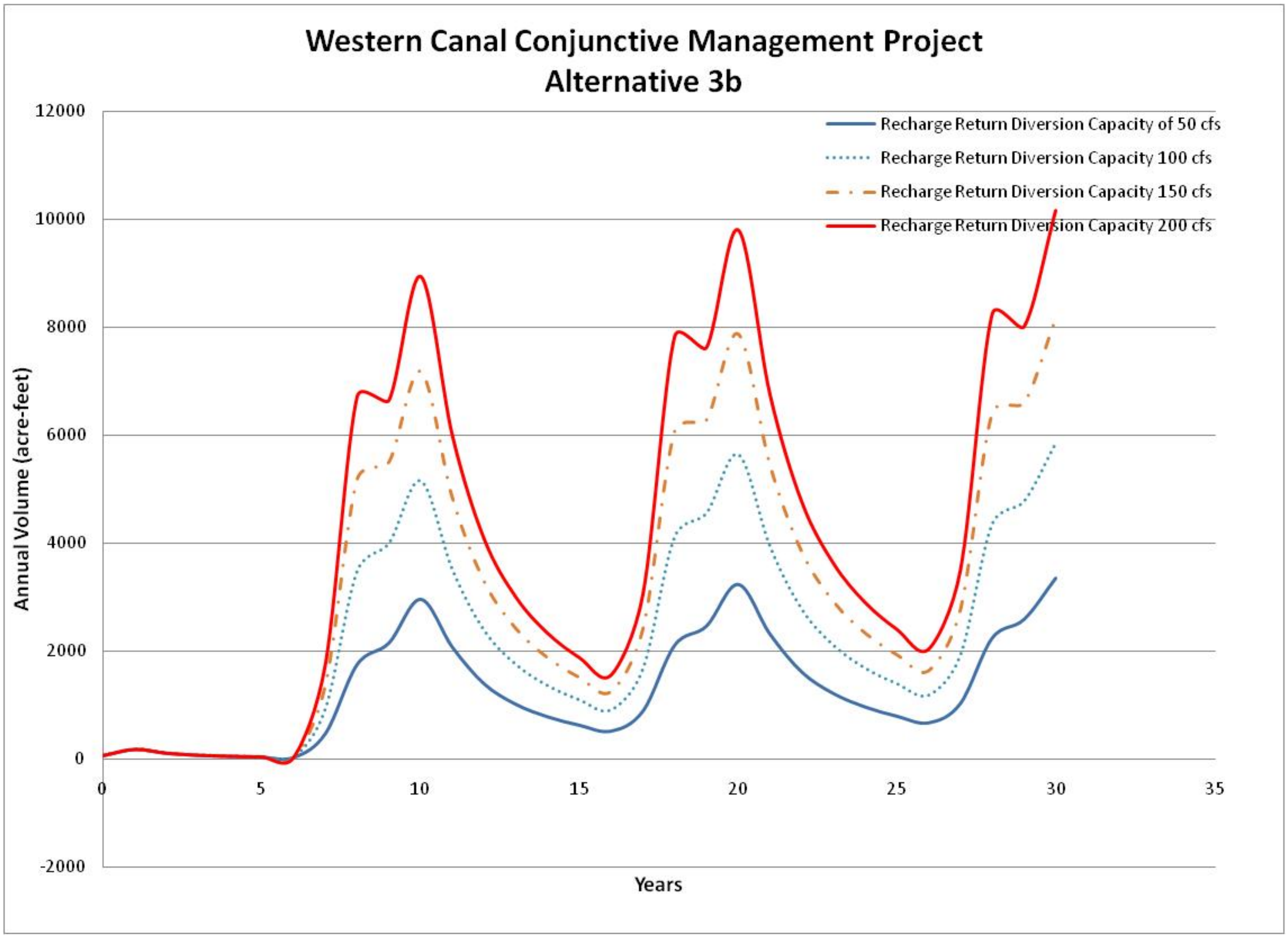
7.7.4 Alternative 3b

Alternative 3b assumes a new appropriation that could utilize the existing diversion and facility, or include a new diversion and facility for the sole purpose of recharge. The available water supply is based on the excess to state protected flows evaluation recently completed for NDNR and described in Section

7.2.4. Diversions were assumed to occur from April through October 15. The actual computed monthly volumes of excess to state protected flows for the period 1988 -1997 were adjusted to account for 5% losses to evaporation/ET to compute the monthly recharge volumes (assumes 0% spills). The volume of water diverted is based on the maximum diversion capacity. To represent a range of potential diversion and facility options, four maximum diversion capacity scenarios were investigated: 50 cfs, 100 cfs, 150 cfs, and 200 cfs.

The monthly recharge for each diversion capacity was then modeled over a 30-year period (repeating the 1988-1997 data) using the AWAS program and an SDF value of 1500 days to estimate the annual recharge return. Because this scenario represents a new use and new appropriation, while the existing use continues as normal, the yield to the river is not adjusted for replacement pumping, baseline recharge returns, baseline returns/spills to the river. Figure 7 illustrates the annual yield to the river estimates for the four diversion capacity scenarios.

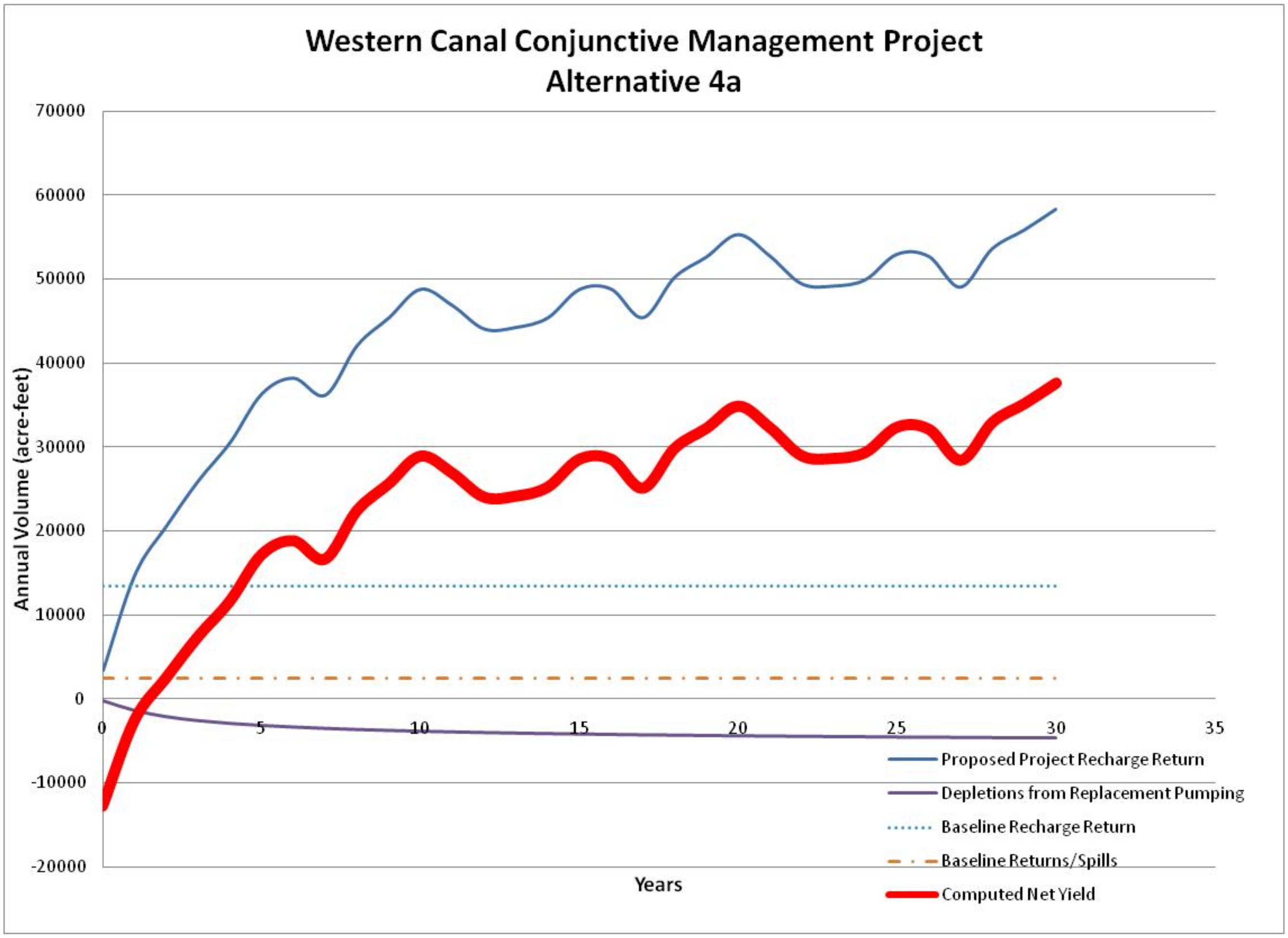
Figure 7 – Western Canal Alternative 3b Net Yield



7.7.5 Alternative 4a

Alternative 4a assumes operation of the facility for recharge only, i.e. no surface water deliveries to producers for irrigation. The historic South Platte River potential diversion volumes (capped at the 176 cfs of the appropriation) March through November for the 1988-1997 period were adjusted to account for 5% losses to evaporation/ET to compute the monthly recharge volumes (assumes 0% spills for the proposed project). This monthly recharge was then modeled over a 30-year period using the AWAS program and an SDF value of 1500 days to estimate the annual recharge return of the proposed project. Figure 8 illustrates the annual recharge volume, annual depletion due to replacement pumping, annual baseline recharge return, annual baseline return/spills, and finally the annual net yield of the project.

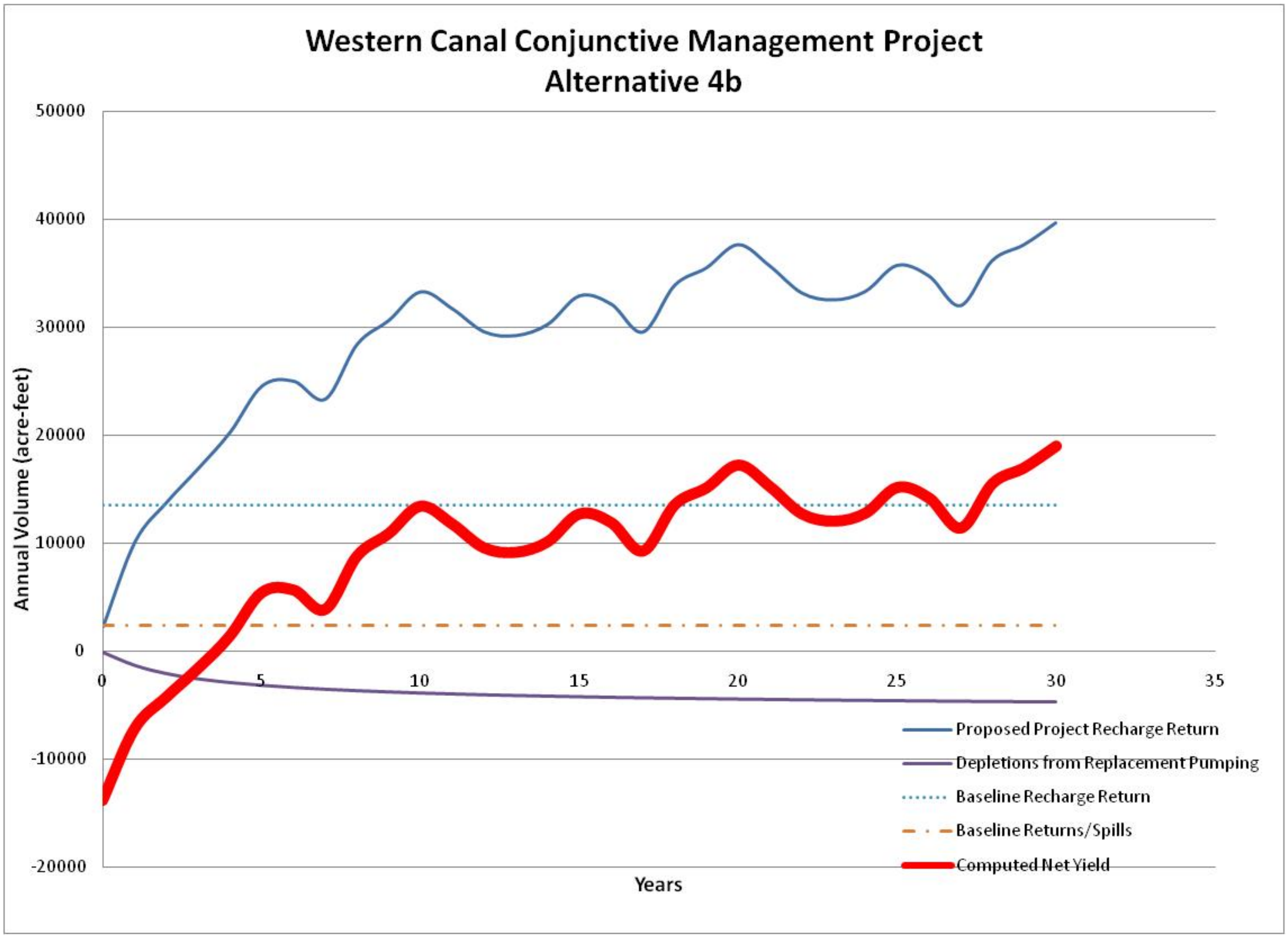
Figure 8 – Western Canal Alternative 4a Net Yield



7.7.6 Alternative 4b

Alternative 4b assumes operation of the facility for recharge only, i.e. no surface water deliveries to producers for irrigation. The historic South Platte River potential diversion volumes (capped at the 176 cfs of the appropriation) April through October 15 for the 1988-1997 period were adjusted to account for 5% losses to evaporation/ET to compute the monthly recharge volumes (assumes 0% spills for the proposed project). This monthly recharge was then modeled over a 30-year period using the AWAS program and an SDF value of 1500 days to estimate the annual recharge return of the proposed project. Figure 9 illustrates the annual recharge volume, annual depletion due to replacement pumping, annual baseline recharge return, annual baseline return/spills, and finally the annual net yield of the project.

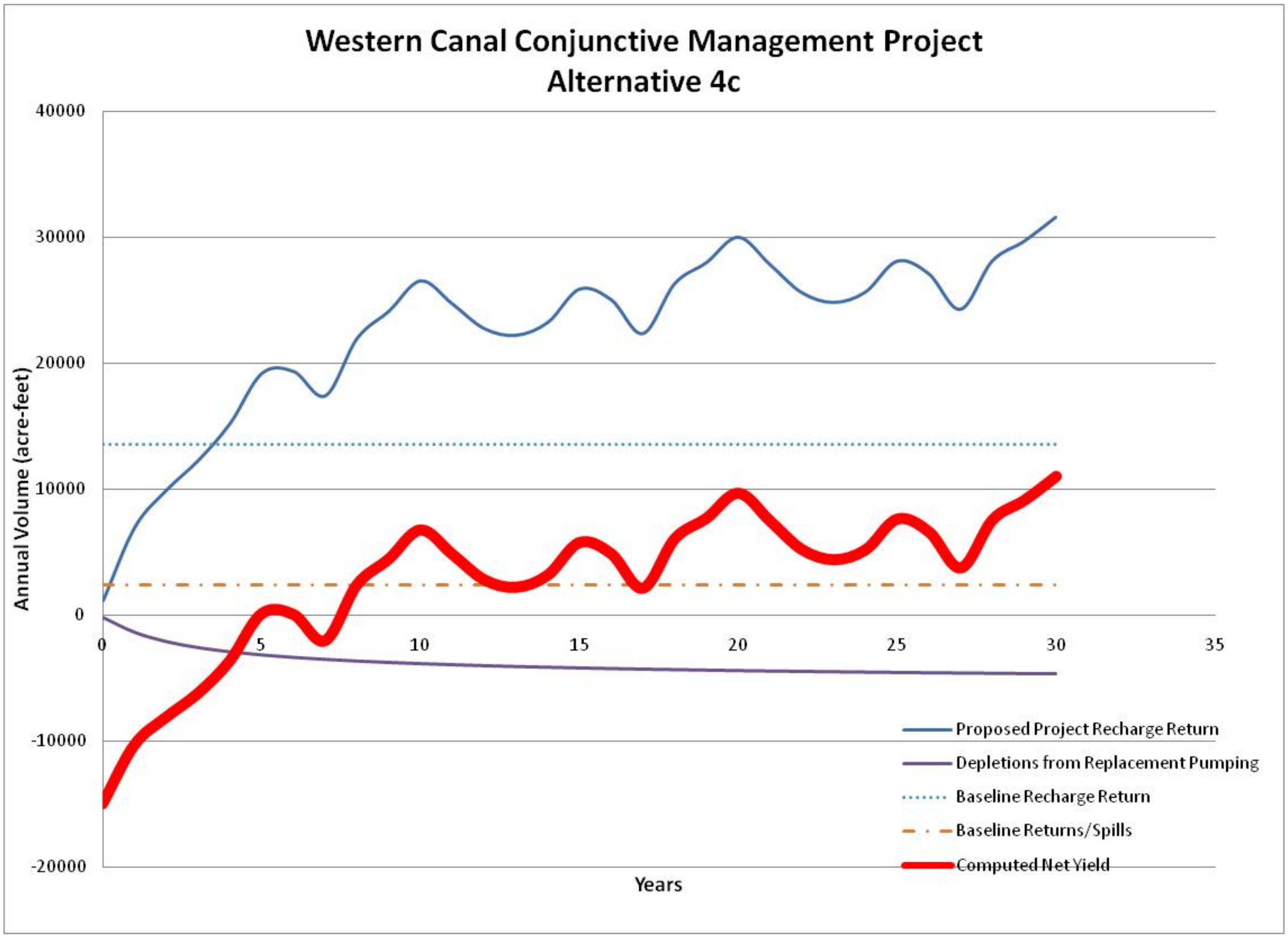
Figure 9 – Western Canal Alternative 4b Net Yield



7.7.7 Alternative 4c

Alternative 4c assumes operation of the facility for recharge only, i.e. no surface water deliveries to producers for irrigation. The historic South Platte River potential diversion volumes (capped at the 176 cfs of the appropriation) over the average diversion period for the 1988-1997 period (May 13 through October 23) were adjusted to account for 5% losses to evaporation/ET to compute the monthly recharge volumes (assumes 0% spills for the proposed project). This monthly recharge was then modeled over a 30-year period using the AWAS program and an SDF value of 1500 days to estimate the annual recharge return of the proposed project. Figure 10 illustrates the annual recharge volume, annual depletion due to replacement pumping, annual baseline recharge return, annual baseline return/spills, and finally the annual net yield of the project.

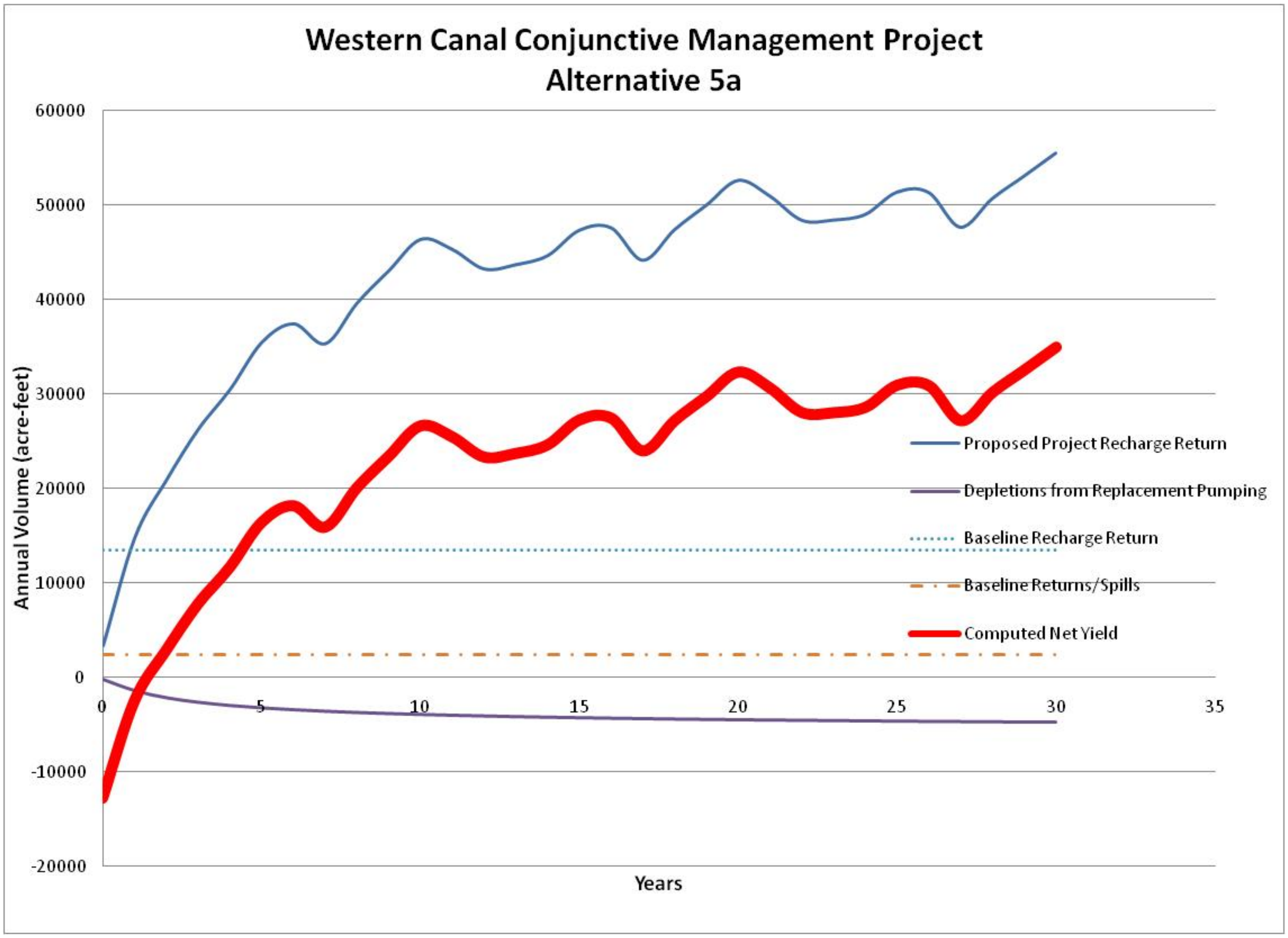
Figure 10 – Western Canal Alternative 4c Net Yield



7.7.8 Alternative 5a

Alternative 5a assumes operation of the facility for recharge only, i.e. no surface water deliveries to producers for irrigation. The historic South Platte River potential diversion volumes (capped at the 176 cfs of the appropriation) for the 1988-1997 period were used for March, April, May, June 1-15, September, October, and November. Actual historic diversion volumes from 1988-1997 were used from June 15 through August 31. The monthly potential diversion volumes were adjusted to account for 5% losses to evaporation/ET to compute the monthly recharge volumes (assumes 0% spills). These monthly recharge values were then modeled over a 30-year period using the AWAS program and an SDF value of 1500 days to estimate the annual recharge return. Figure 11 illustrates the annual recharge volume, annual depletion due to replacement pumping, annual baseline recharge return, annual baseline return/spills, and finally the annual net yield of the project.

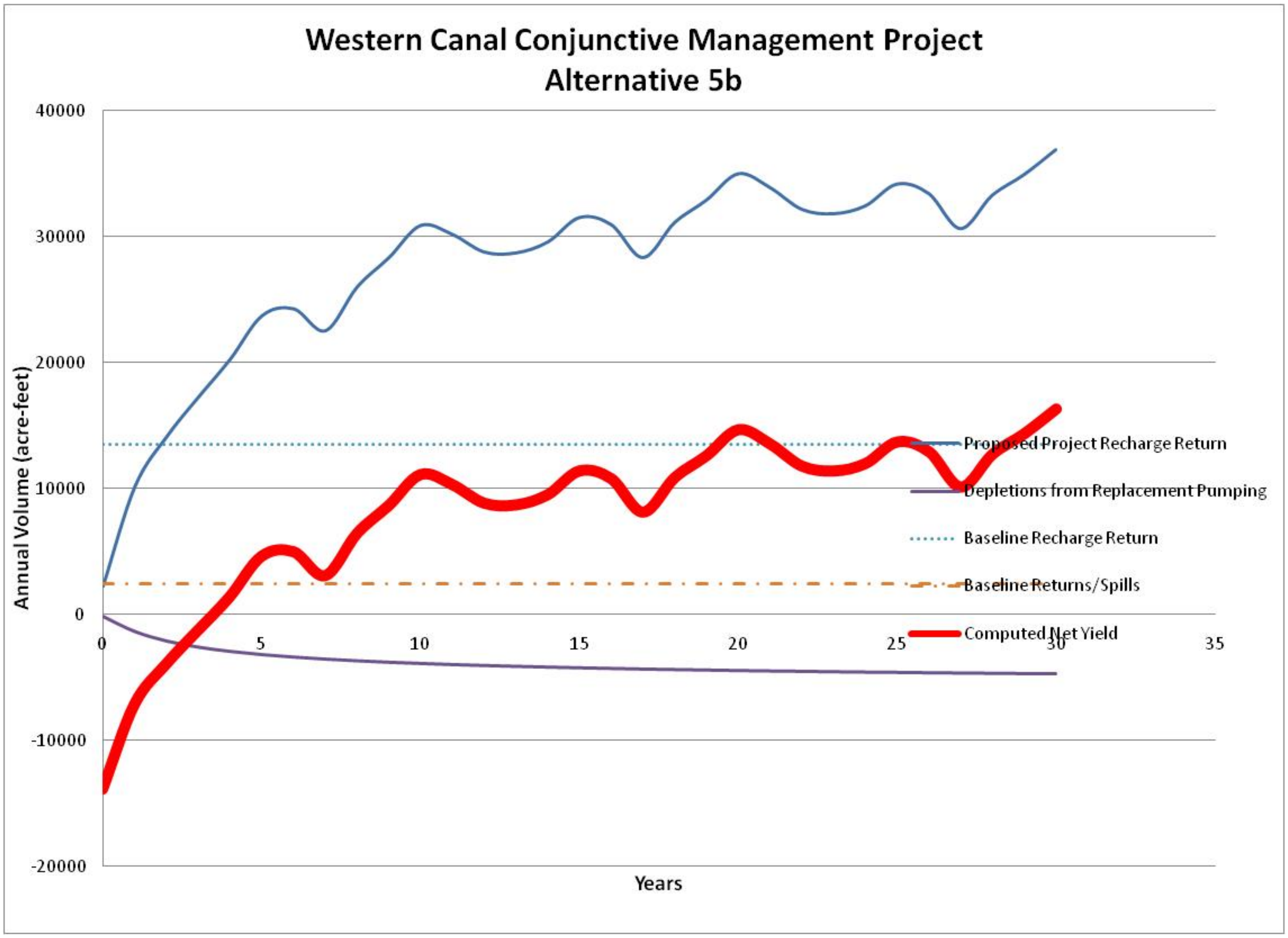
Figure 11 – Western Canal Alternative 5a Net Yield



7.7.9 Alternative 5b

Alternative 5b assumes operation of the facility for recharge only, i.e. no surface water deliveries to producers for irrigation. The historic South Platte River potential diversion volumes (capped at the 176 cfs of the appropriation) for the 1988-1997 period were used for April, May, June 1 through June 15, September, and October 1 through October 15. Actual historic diversion volumes from 1988-1997 were used from June 15 through August 31. The monthly potential diversion volumes were adjusted to account for 5% losses to evaporation/ET to compute the monthly recharge volumes (assumes 0% spills). These monthly recharge values were then modeled over a 30-year period using the AWAS program and an SDF value of 1500 days to estimate the annual recharge return. Figure 12 illustrates the annual recharge volume, annual depletion due to replacement pumping, annual baseline recharge return, annual baseline return/spills, and finally the annual net yield of the project.

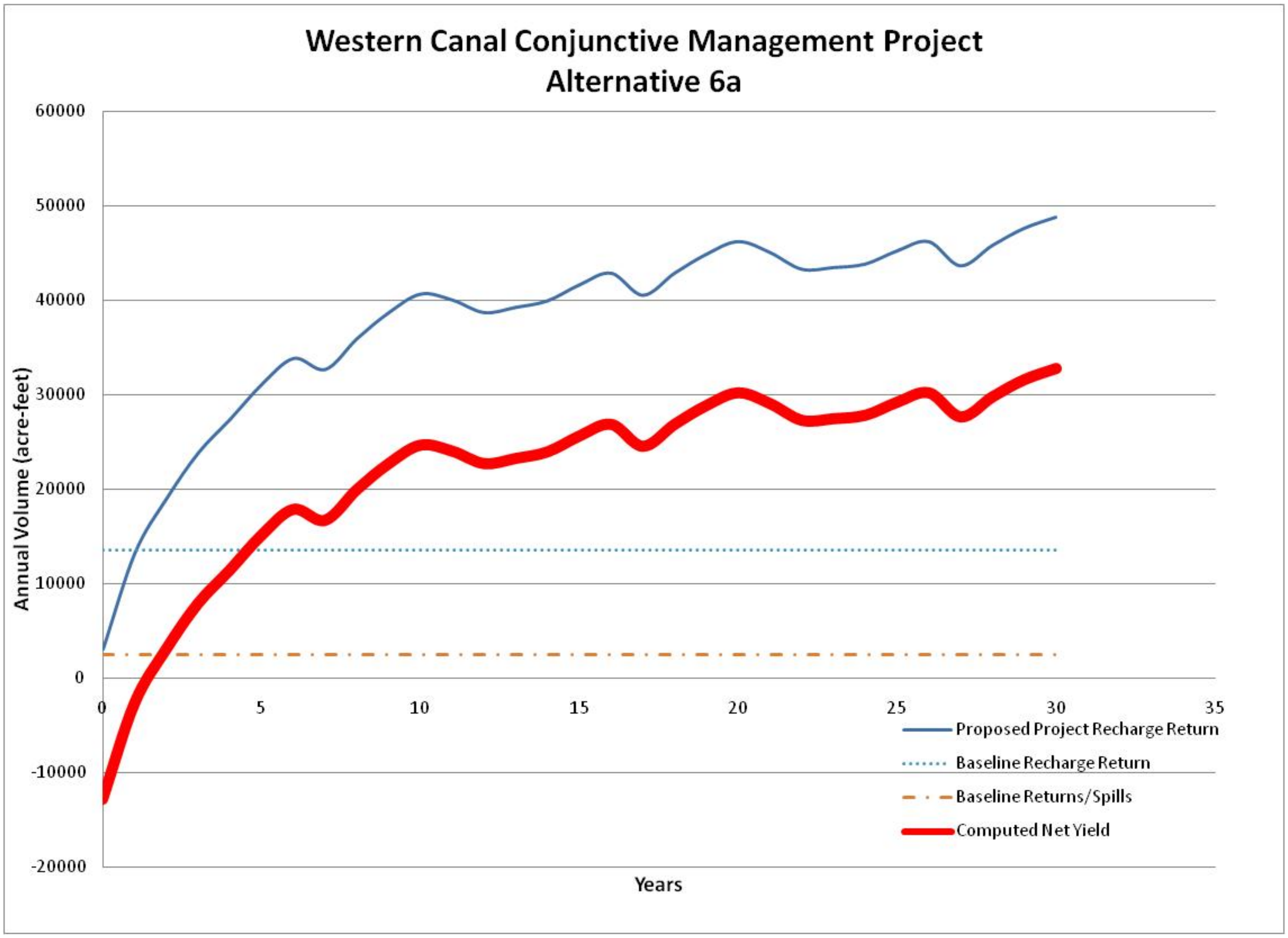
Figure 12 – Western Canal Alternative 5b Net Yield



7.7.10 Alternative 6a

Alternative 6a assumes operation of the facility for recharge during the non-irrigation season (March 1 through June 15 and September 1 through November 30. During the irrigation season, surface water deliveries will be made to producers for irrigation, therefore no replacement pumping is included in the net yield computations. The historic monthly volumes at the Julesburg gage from 1988-1997 for March 1 through June 15 and September 1 through November 30 will be used, capped at the maximum diversion capacity of 176 cfs. The monthly diversion volumes were adjusted to account for 5% losses to evaporation/ET to compute the monthly recharge volumes (assumes 0% spills).). During the irrigation season, the historic recharge estimate from Section 7.6.1 (3) will be used for the recharge estimate. This monthly recharge was then modeled over a 30-year period using the AWAS program and an SDF value of 1500 days to estimate the annual recharge return. Figure 13 illustrates the annual recharge volume, annual baseline recharge return, annual baseline return/spills, and finally the annual net yield of the project

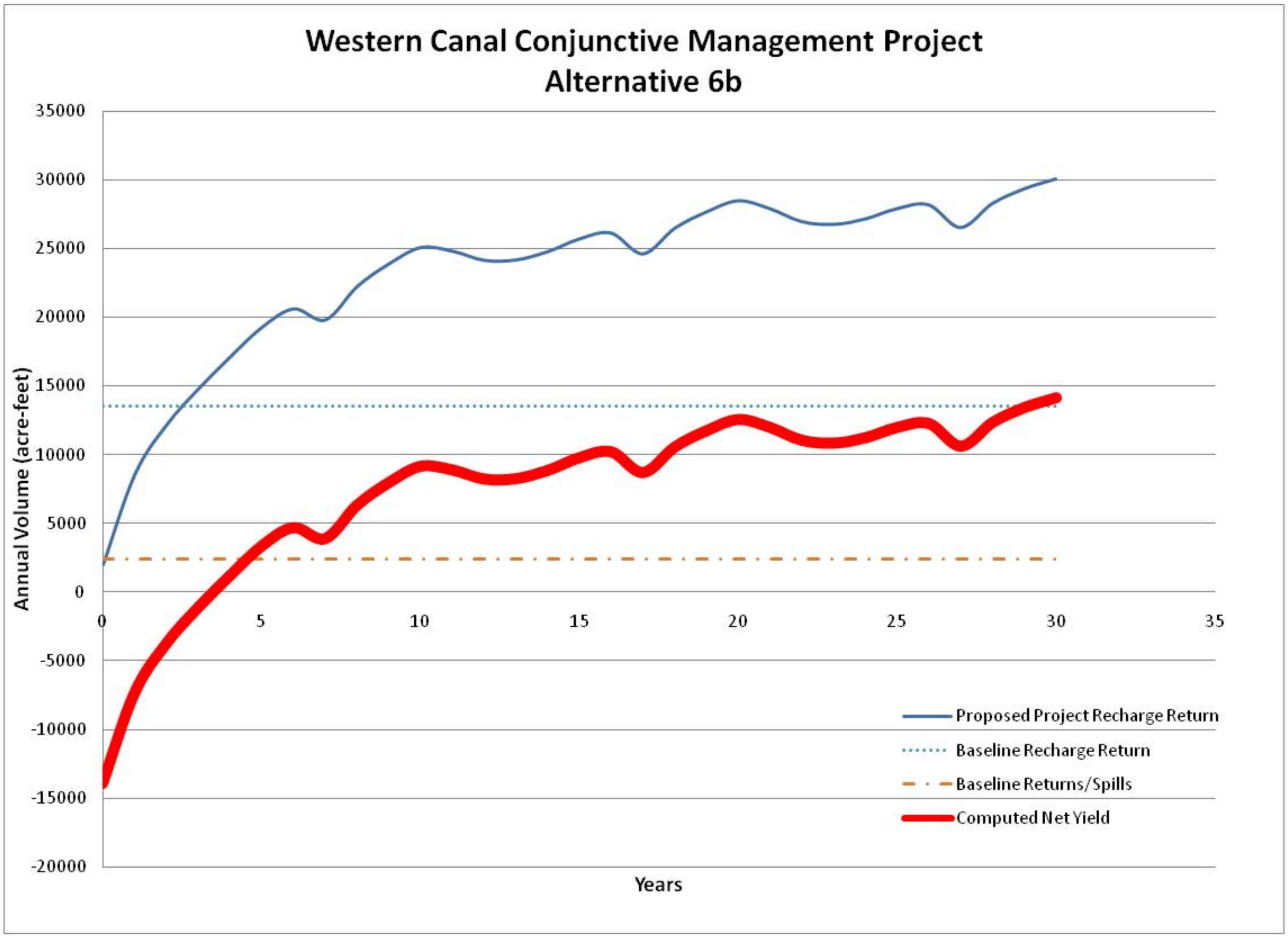
Figure 13 – Western Canal Alternative 6a Net Yield



7.7.11 Alternative 6b

Alternative 6b assumes operation of the facility for recharge during the non-irrigation season (April 1 through June 15 and September 1 through October 15. During the irrigation season, surface water deliveries will be made to producers for irrigation, therefore no replacement pumping is included in the net yield computations. The historic monthly volumes at the Julesburg gage from 1988-1997 for April 1 through June 15 and September 1 through October 15 will be used, capped at the maximum diversion capacity of 176 cfs. The monthly diversion volumes were adjusted to account for 5% losses to evaporation/ET to compute the monthly recharge volumes (assumes 0% spills).). During the irrigation season, the historic recharge estimate from Section 7.6.1 (3) will be used for the recharge estimate. This monthly recharge was then modeled over a 30-year period using the AWAS program and an SDF value of 1500 days to estimate the annual recharge return. Figure 14 illustrates the annual recharge volume, annual baseline recharge return, annual baseline return/spills, and finally the annual net yield of the project

Figure 14 – Western Canal Alternative 6b Net Yield



7.7.12 Summary of Alternatives

The conceptual groundwater recharge projects' yields are part of a continuum. In order to facilitate a comparison of alternatives, the computed net yields from years 10 through 20 (11 years total) will be used as a metric to evaluate the project alternatives. The results are provided in Table 15.

Table 15: Summary of Project Alternatives

Alternative Name	Water Supply Concept*	Diversion Operations Concept**	Replacement Pumping?	Notes	Total Yield*** (Acre-Ft)	Average Annual Yield**** (Acre-Ft)
1	Historic Diversion	Actual Historic Dates	Y	System operated solely as a recharge facility	-7,172	-652
2	Historic Diversions and Excess to State Protected Flows	March 1 – Nov. 30	NA	Assumes new appropriation, normal Western operations, diversions limited to excess of historical diversion up to capacity	36,770	3,340
3a	Excess to State Protected Flows	March 1 – Nov. 30	NA	Assumes new appropriation, normal Western operations, looks at 50, 100, 150, and 200 cfs diversion capacities	48,560^	4,420^
3b	Excess to State Protected Flows	April 1 – Oct. 15	NA	Assumes new appropriation, normal Western operations, looks at 50, 100, 150, and 200 cfs diversion capacities	45,010^	4,090^
4a	Historic S. Platte Flow	March 1 –Nov. 30	Y	System operated solely as a recharge facility	308,950	28,090
4b	Historic S. Platte Flow	April 1 – Oct. 15	Y	System operated solely as a recharge facility	134,120	12,190
4c	Historic S. Platte Flow	May 13 – Oct. 23	Y	System operated solely as a recharge facility	55,700	5,060
5a	Historic Diversions June 15-Aug. 31; Historic S. Platte Flow March–June 15, Sept. 1–Nov. 30	March 1 – Nov. 30	Y	System operated solely as a recharge facility	291,840	26,531
5b	Historic Diversion June 15-Aug. 31; Historic S. Platte Flow April – June 15, Sept. 1 – October 15	April 1 – Oct. 15	Y	System operated solely as a recharge facility	117,010	10,640
6a	Historic Diversions June 15-Aug. 31; Historic S. Platte Flow March–June 15, Sept. 1–Nov. 30	March 1 – Nov. 30	N	Non-irrigation operation as a recharge facility, normal deliveries during irrigation season	281,940	25,630
6b	Historic Diversions June 15-Aug. 31; Historic S. Platte Flow April–June 15, Sept. 1–Oct. 15	April 1 – Oct. 15	N	Non-irrigation operation as a recharge facility, normal deliveries during irrigation season	107,110	9,740

* Water supply concepts discussed in Section 7.2
**Diversion operation concepts discussed in Section 7.3
***Total yield from years 10 through 20 of groundwater recharge project operation
**** Annual yield from years 10 through 20 of groundwater recharge project operation
^ Values are based on 150 cfs diversion capacity

7.8 Economics

For purposes of this case study of Western Canal, the economic considerations of alternative 5a will be evaluated. Alternative 5a assumes operation of the existing facility for recharge only, i.e. no surface water deliveries to producers for irrigation. Costs will be developed for this example using Site 4 as the location of the intentional recharge pits. The economic considerations for this alternative have been broken down into capital costs, operation and maintenance costs, replacement pumping costs, and producer revenues.

7.8.1 Capital Costs

Site 4 is bounded on the east and west sides by canal laterals from the main Western Canal. The major cost items for developing the recharge facilities at Site 4 are summarized in Table 16. Unit cost estimates were based on a variety of sources that included bid tabulations for similar construction, published prices from vendor catalogs and websites, and engineering experience on similar construction projects.

Table 16: Summary of Capital Costs

Description	Unit	Unit Cost	Quantity	Total Cost
Land	Acre	$3,000[23]	140	$420,000
Canal/Lateral Diversion Structures/Gates – Installed	Each	$9,000	4	$36,000
Excavation for Recharge Basins	Cubic Yard	$1.50	1,200,000[24]	$1,800,000
Discharge structures for Recharge Basins – Installed	Each	$8,000	3	$24,000
Canal/Lateral Improvements	Each	$10,000	2	$20,000
48-inch pipe - Installed	Linear Ft	$100	1,500	$150,000
				$2,420,000
Construction Mobilization/Demobilization	% of capital cost	3%		$75,000
Engineering and Permitting	% of capital cost	10%		$242,000
Contingencies	% of capital cost	20%		$484,000
TOTAL				**$3,220,000**

7.8.2 Operation and Maintenance Costs

Operation and maintenance costs would consist primarily of maintaining the canal, diversion structures, and recharge facilities. Some increased maintenance to facilities may be expected if the system is operated in the early and late seasons. Overall, maintenance costs are expected to be in the range of 0.5% to 1% of construction costs.

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[23] Estimate based on conversations with TPNRD staff, March 2011 and *Nebraska Farm Real Estate Market Highlights 2009-2010*, June 2010

[24] Quantity based on average excavation depth of 6-ft for the 3 - 40-acre recharge pits

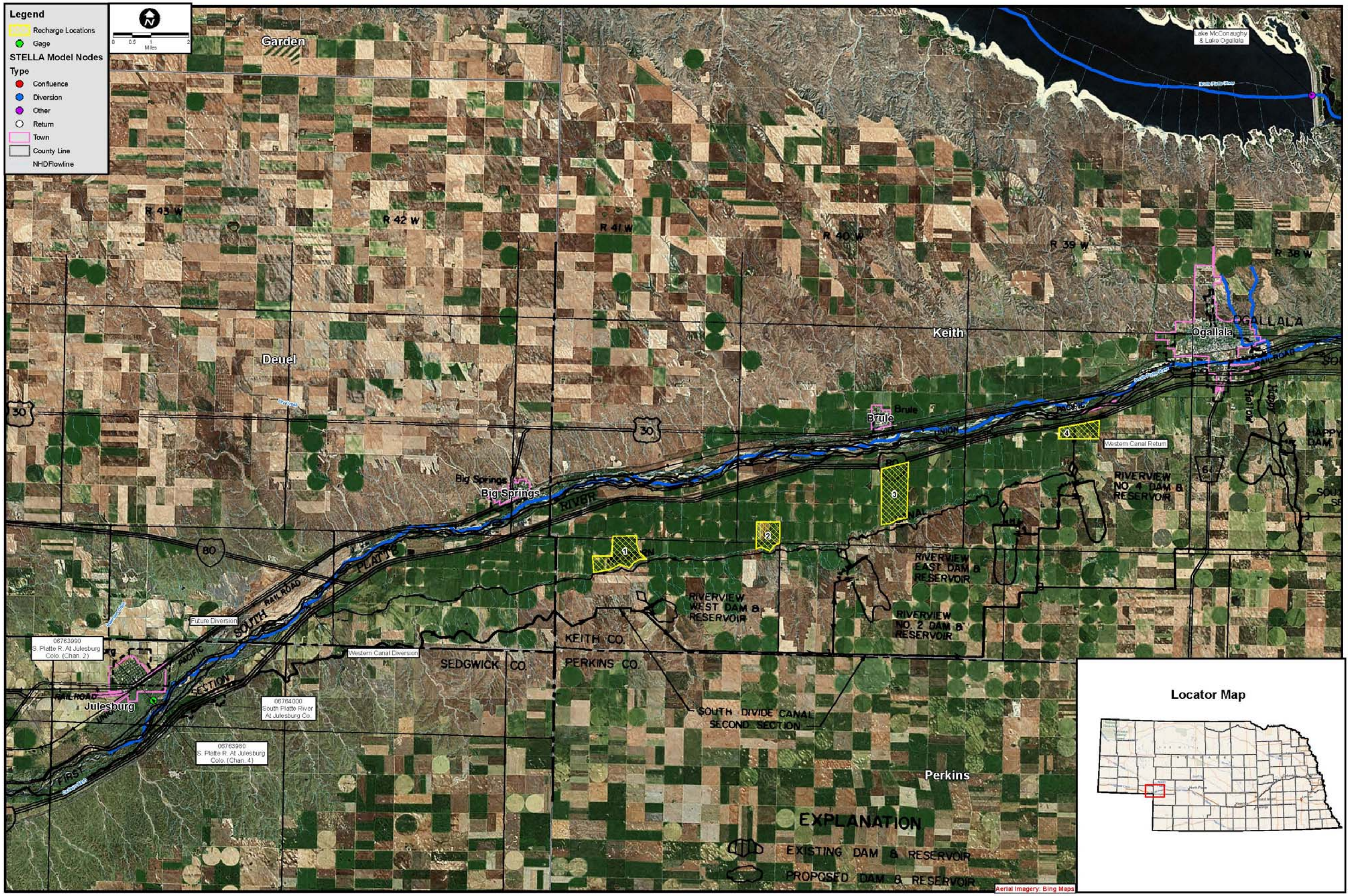
7.8.3 Replacement Pumping Costs

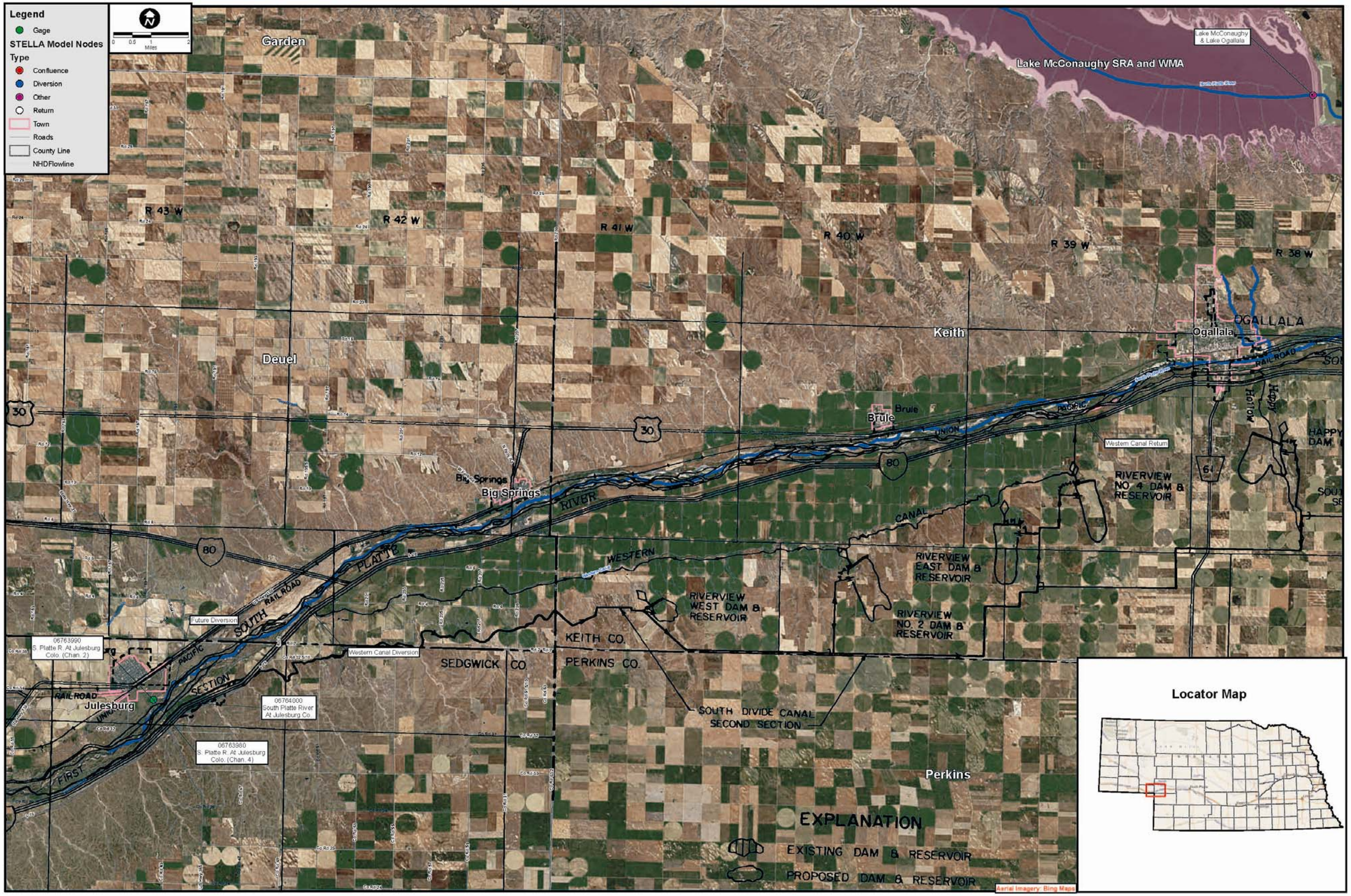
Replacement pumping costs reflect the additional cost of pumping groundwater to replace lost surface water deliveries. The majority of irrigated lands on the Western Canal system use pivot irrigation systems for both surface and groundwater application. Based on discussions with TPNRD staff, it is estimated that the net cost for replacement pumping is zero. The relatively shallow aquifer will require minimum additional lift when compared to the surface water source, and therefore pumping cost increases are minimal. These minimal cost increases are further offset by the decreased O&M costs associated with using groundwater instead of surface water as the source for pivot irrigation systems.

7.8.4 Producer Revenues

Alternative 5a assumes full replacement of lost surface water by increased groundwater pumping. As such, no deficit in crop irrigation requirements are anticipated, resulting in crop yields and gross producer revenue remaining constant. Producer net revenues may be impacted and are dependent on funding and financing of project costs.

Appendix A – Western Canal Field Visit Maps and Photos


Legend
Recharge Locations
Gage
STELLA Model Nodes
Type
Confluence
Diversion
Other
Return
Town
County Line
NHDFlowline
0 0.5 1 2
Miles
Garden
Lake McConaughy & Lake Ogallala
R 43 W
R 42 W
R 41 W
R 40 W
R 39 W
R 38 W
Keith
Ogallala
OGALLALA
Deuel
30
Brule
Big Springs
SOUTH PLATTE RIVER
UNION PACIFIC RAIL ROAD
80
Western Canal Return
RIVERVIEW NO. 4 DAM & RESERVOIR
RIVERVIEW EAST DAM & RESERVOIR
RIVERVIEW WEST DAM & RESERVOIR
RIVERVIEW NO. 2 DAM & RESERVOIR
1
2
3
4
Future Diversion
06763990
S. Platte R. At Julesburg Colo. (Chan. 2)
Western Canal Diversion
KEITH CO.
SEDGWICK CO.
PERKINS CO.
Julesburg
06764000
South Platte River At Julesburg Co.
06763980
S. Platte R. At Julesburg Colo. (Chan. 4)
SOUTH DIVIDE CANAL SECOND SECTION
FIRST SECTION
Perkins
EXPLANATION
EXISTING DAM & RESERVOIR
PROPOSED DAM & RESERVOIR
Aerial Imagery: Bing Maps
Locator Map


Legend
● Gage
STELLA Model Nodes
Type
● Confluence
● Diversion
● Other
○ Return
Town
Roads
County Line
NHDFlowline
0 0.5 1 2
Miles
Garden
Lake McConaughy SRA and WMA
Lake McConaughy & Lake Ogallala
R 43 W
R 42 W
R 41 W
R 40 W
R 39 W
R 38 W
Deuel
Keith
Ogallala
OGALLALA
Brule
Big Springs
30
80
61
SOUTH PLATTE RIVER
UNION PACIFIC RAILROAD
WESTERN CANAL
Western Canal Return
Western Canal Diversion
Future Diversion
RIVERVIEW NO. 4 DAM & RESERVOIR
RIVERVIEW EAST DAM & RESERVOIR
RIVERVIEW WEST DAM & RESERVOIR
RIVERVIEW NO. 2 DAM & RESERVOIR
HAPPY HOLLOW DAM
06763990 S. Platte R. At Julesburg Colo. (Chan. 2)
06764000 South Platte River At Julesburg Co.
06763980 S. Platte R. At Julesburg Colo. (Chan. 4)
Julesburg
FIRST SECTION
KEITH CO.
SEDGWICK CO.
PERKINS CO.
SOUTH DIVIDE CANAL SECOND SECTION
Perkins
EXPLANATION
EXISTING DAM & RESERVOIR
PROPOSED DAM & RESERVOIR
Aerial Imagery: Bing Maps
Locator Map

Properties for predominant Soils for “above canal” sites

1307—Bayard very fine sandy loam, 1 to 3 percent slopes

- *Slope:* 1 to 3 percent
- *Depth to restrictive feature:* More than 80 inches
- *Drainage class:* Well drained
- *Capacity of the most limiting layer to transmit water (Ksat):* High (2.00 to 6.00 in/hr)
- *Depth to water table:* More than 80 inches
- *Frequency of flooding:* None
- *Frequency of ponding:* None
- *Calcium carbonate, maximum content:* 10 percent
- *Available water capacity:* High (about 9.5 inches)

5822—Duroc loam, terrace, 0 to 1 percent slopes

- *Slope:* 0 to 1 percent
- *Depth to restrictive feature:* More than 80 inches
- *Drainage class:* Well drained
- *Capacity of the most limiting layer to transmit water (Ksat):* Moderately high to high (0.60 to 2.00 in/hr)
- *Depth to water table:* More than 80 inches
- *Frequency of flooding:* None
- *Frequency of ponding:* None
- *Calcium carbonate, maximum content:* 10 percent
- *Maximum salinity:* Nonsaline (0.0 to 2.0 mmhos/cm)
- *Sodium adsorption ratio, maximum:* 2.0
- *Available water capacity:* High (about 9.6 inches)

8581—Wann fine sandy loam, rarely flooded

- *Slope:* 0 to 2 percent
- *Depth to restrictive feature:* More than 80 inches
- *Drainage class:* Somewhat poorly drained
- *Capacity of the most limiting layer to transmit water (Ksat):* High (2.00 to 6.00 in/hr)
- *Depth to water table:* About 18 to 42 inches
- *Frequency of flooding:* Rare
- *Frequency of ponding:* None
- *Calcium carbonate, maximum content:* 5 percent
- *Maximum salinity:* Nonsaline (0.0 to 2.0 mmhos/cm)
- *Sodium adsorption ratio, maximum:* 10.0
- *Available water capacity:* Moderate (about 8.4 inches)

Properties for predominant Soils for “below canal” sites

1814—Satanta loam, 3 to 6 percent slopes

- *Slope:* 3 to 6 percent
- *Depth to restrictive feature:* More than 80 inches
- *Drainage class:* Well drained
- *Capacity of the most limiting layer to transmit water (Ksat):* Moderately high to high (0.20 to 2.00 in/hr)
- *Depth to water table:* More than 80 inches
- *Frequency of flooding:* None
- *Frequency of ponding:* None
- *Calcium carbonate, maximum content:* 15 percent
- *Available water capacity:* High (about 10.0 inches)

1010—Bankard loamy sand, channeled, frequently flooded

- *Slope:* 0 to 2 percent
- *Depth to restrictive feature:* More than 80 inches
- *Drainage class:* Somewhat excessively drained
- *Capacity of the most limiting layer to transmit water (Ksat):* High to very high (5.95 to 19.98 in/hr)
- *Depth to water table:* More than 80 inches
- *Frequency of flooding:* Frequent
- *Frequency of ponding:* None
- *Calcium carbonate, maximum content:* 10 percent
- *Maximum salinity:* Nonsaline (0.0 to 2.0 mmhos/cm)
- *Available water capacity:* Low (about 3.8 inches)

1507—Altvan-Dix complex, 6 to 30 percent slopes

- *Slope:* 6 to 15 percent
- *Depth to restrictive feature:* More than 80 inches
- *Drainage class:* Well drained
- *Capacity of the most limiting layer to transmit water (Ksat):* Moderately high to high (0.20 to 2.00 in/hr)
- *Depth to water table:* More than 80 inches
- *Frequency of flooding:* None
- *Frequency of ponding:* None
- *Calcium carbonate, maximum content:* 10 percent
- *Available water capacity:* Moderate (about 6.7 inches)

1824—Satanta-Dix complex, 3 to 9 percent slopes

- *Slope:* 3 to 9 percent
- *Depth to restrictive feature:* More than 80 inches
- *Drainage class:* Well drained
- *Capacity of the most limiting layer to transmit water (Ksat):* Moderately high to high (0.20 to 2.00 in/hr)
- *Depth to water table:* More than 80 inches
- *Frequency of flooding:* None
- *Frequency of ponding:* None
- *Calcium carbonate, maximum content:* 15 percent
- *Available water capacity:* High (about 10.0 inches)

Potential Recharge Site #3 – Clockwise Panoramic (begin looking South)

Photo 1 – Looking South

Photo 2 – Looking Southwest

Photo 3 – Looking West

Photo 4 – Looking West

Photo 5 – Looking Northwest

Photo 6 – Looking North

Photo 7 – Looking Northeast

Photo 8 – Looking East

Photo 9 – Looking Southeast

Photo 10 – Looking Northwest

Photo 11 – Looking North

Photo 12 – Looking Northeast

Approximately 1.5 miles west of Potential Recharge Site #1 – Clockwise Panoramic (begin looking South)

Photo 13 – Looking South

Photo 14 – Looking Southwest

Photo 15 – Looking West

Photo 16 – Looking Northwest

Photo 17 – Looking North

Photo 18 – Looking Northeast

Palser’s Potential Recharge Site

Photo 19

Photo 20

Photo 21

Photo 22

Western Canal Diversion

Photo 23 – South Platte River at Western Canal, Looking Upstream

Photo 24 – Upstream Face of South Platte River Headgates

Photo 25 – Western Canal, Looking Downstream

Photo 26 – South Platte River, Looking Upstream

Photo 27 – Upstream Face of Western Canal Intake Structure

Photo 28 – South Platte River, Looking Downstream

Photo 29 - South Platte River, Looking Downstream

Photo 30 - South Platte River, Looking Downstream

Photo 31 – Downstream Face of Headgates

Photo 32 – Downstream Face of Headgates

Photo 33 – Downstream Face of Headgates

Photo 34 – Downstream Face of Headgates

Photo 35 – Downstream Face of Headgates

Photo 36 – South Platte River, Looking Upstream