PLATTE RIVER RECOVERY IMPLEMENTATION PROGRAM
Nebraska Ground Water Recharge Pre-Feasibility Study

PLATTE RIVER
RECOVERY IMPLEMENTATION PROGRAM

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the Water Advisory Committee, Hahn Water Resources LLC,
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August 2010

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I. EXECUTIVE SUMMARY

The objectives of this pre-feasibility study were to 1) refine yield and cost estimates for the "Nebraska Ground Water Recharge" project described in the Platte River Recovery Implementation Program (Program) 2000 Reconnaissance-Level Water Action Plan (WAP) (Boyle 2000); and 2) identify the most feasible ground water recharge concepts and project configurations that should be carried forward for additional study if authorized by the Program Governance Committee. After initial consideration of potential recharge concepts and sites, it was determined that yield of a ground water recharge project could be increased by including applicable elements of ground water management. Additionally, the study area for potential recharge projects was expanded to include recharge sites along the Phelps County Canal, and other locations not along an existing canal, where diversions of excesses to Program target flows and Nebraska instream flows could be made using "headgate wells" close to the Platte River.

A suite of ground water recharge concepts was developed with the help of a ground water recharge technical work group. Each of the concepts included one or more methods to divert excess flows from the Platte River, types of ground water recharge, and means of recovering ground water for yield to reduce shortages to Program target flows. The array of project components is summarized in **Figure 1**.

Figure 1. Ground Water Recharge Project Components

Divert Excesses	Recharge	Recovery
• Surface Water Canal • Well Close to Platte River	• Constructed Recharge Basin • Canal Seepage	• Natural Ground Water Flow • Active Pumping • Pumping of High Water Tables • In-lieu Pumping

Four of the most feasible ground water recharge concepts were identified with input from the ground water recharge technical work group. The four concepts were various combinations of the methods listed above for diversion of excesses to target flows, ground water recharge, and recovery. A "long list" of potential ground water recharge project configurations was identified, and qualitative screening criteria were used to pare the long list down to a "short list" of project configurations to be analyzed in detail. One project configuration for each of the four general concepts was carried forward for detailed analyses. The "short list" of project configurations was developed using the following screening criteria:

1. Distance to Platte River ideal for ground water return flows that would maximize project yield through the use of ground water return flows from intentional recharge projects.
2. Soil type and depth to ground water that would maximize recharge rates.
3. Operational flexibility that would maximize recharge (e.g., maximum length of recharge season including winter months when excess flows are highest).
4. Highest yield to cost ratio, based on qualitative assessment (e.g., given similar yield, sites with generally lower cost infrastructure were prioritized over those with more costly infrastructure).

Consideration of the above factors resulted in selection of the configurations listed in **Table 1** for analysis in this study. Additional project configurations were considered, but were determined to be less feasible (i.e., lower yield to cost ratio) than the five project configurations selected for detailed analyses.

Table 1. Project Configurations Analyzed in Detail

Name	Means of Diversion	Means of Recharge	Means of Recovery
Phelps 9.7	Phelps Co Canal	Constructed recharge basins north of Phelps Co Canal about 9.7 miles downstream from the J2 Return, and Phelps Co. Canal seepage en route to constructed recharge basins	Ground water return flows, augmented with active pumping if needed to unnamed drainage at Phelps 9.7 location
Thirty Mile	Alluvial headgate wells	Constructed recharge basins on fallow lands south of the Platte River	Ground water return flows
Gothenburg Canal south of Golf Course	Gothenburg Canal	Constructed recharge basins south of Wild Horse Golf Course and Gothenburg Canal seepage en route to constructed recharge basins	Ground water return flows, augmented with active pumping to Gothenburg Canal and Lake Helen hydropower tailrace as needed
B1 Reservoir	Gothenburg Canal	Gothenburg Canal seepage and seepage at B1 Reservoir	Active pumping to Buffalo Creek and/or in-lieu pumping
High Ground Water Southwest of Overton	Dawson County Canal (as needed)	Dawson County Canal seepage (as needed)	Pumping of high ground water southwest of Overton delivered to Platte River via Spring Creek

Yield for each of the five project configurations was estimated as yield from return flows resulting from intentional recharge from canal seepage and constructed recharge basins, determined using the “effective SDF” approach in the Alluvial Water Accounting System (IDS 2009), plus the yield that would occur as a result of ground water management alternatives combined with recharge projects. Yield was further limited to the volume of return flows from recharge operations that would reduce shortages to monthly Platte River target flows. Cost estimates were also developed for each of the project configurations on a preliminary feasibility level. Yield and cost estimates for the project configurations analyzed in detail are summarized in **Table 2**.

Table 2. Nebraska Ground Water Recharge Yield and Cost Estimate Summary

Project	Diversions (AFY)	Yield[1] (AFY)		Efficiency[2]		Unit Cost[4] ($/AFY)
		Project Location	Grand Island[3]	Project Location	Grand Island	
Phelps 9.7 (Type I)	8,600	3,995	3,321	46%	39%	$17
Thirty Mile (Type II)	9,289	4,185	3,490	45%	38%	$89
Gothenburg Canal south of Golf Course, Canal Diversions Only (Type I)	9,297	4,254	3,523	46%	38%	$16
Gothenburg Canal south of Golf Course, Canal and Headgate Well Diversions (Type I/II)	9,297	4,254	3,523	46%	38%	$31
B1 Reservoir (Type III)	1,676	1,021	712	61%	42%	$56
High Ground Water Southwest of Overton (Type IV)	5,141	4,962	4,229	97%	82%	$26

Notes:

[1] Yield defined as volume of return flows that may reduce shortages to Program target flows (i.e., minimum of monthly return flows and shortages to target flows).

[2] Efficiency calculated as yield divided by diversions.

[3] Yield at Grand Island was based on yield at Project location, routed to Grand Island using the WMC Loss Model updated under the Water Management Study. For project configurations where return flows would accrue to the Platte River downstream of Overton (Phelps 9.7 and High Ground Water Southwest of Overton), yield was reduced to reflect the portion of the Overton to Grand Island reach that would be affected by the return flows.

[4] Unit cost based on project yield (i.e., reductions to target flow shortages) at Grand Island for the 1947-1994 scoring period.

A summary of the key findings from this pre-feasibility study is provided below:

1. Potential sites for ground water recharge projects exist in Dawson and Phelps counties, including sites along the Gothenburg, Dawson County, and Phelps County canals.
2. Ground water recharge projects in Nebraska may have lower yields than similar projects in Colorado (e.g., Tamarack) because of a generally shallow and flat ground water table.
3. Elements of ground water management can be added to ground water recharge projects to increase potential yield.
4. Diversion of excesses to target flows could be made using some combination of existing surface water canals and/or alluvial "headgate" wells.
5. Ground water recharge could be achieved over a broad area via intentional ground water recharge from canal seepage, and/or at discrete locations using constructed recharge basins.
6. Yield of ground water recharge projects may be higher than the yield anticipated in the PRRIP 2000 WAP.
7. Yield of ground water recharge projects will be dependent on site-specific conditions, including soil type and depth to water.
8. Winter operations in irrigation canals may be limited by icing problems, which could be minimized by continuously cycling water through the canals and/or diverting warmer alluvial ground water to the canals using "headgate wells."
9. The distance from potential recharge sites to the Platte River would affect the timing of ground water return flows to the Platte River.

Based on the results of this preliminary feasibility analysis, feasibility-level analyses are recommended for the Gothenburg Canal south of Golf Course and Phelps 9.7 sites including the following steps:

1. Permitting and institutional coordination – establish project sponsors (NPPD and/or CNPPID), lease water for demonstration project, and initiate permitting process for potential full-scale project due to long duration of permitting process.
2. Landowner coordination – obtain land access for feasibility-level fieldwork.
3. Feasibility-level fieldwork – install monitoring wells to refine pre-feasibility assumptions regarding depth to ground water, and complete aquifer testing in existing irrigation supply wells to refine pre-feasibility assumptions regarding aquifer properties used to estimate recharge project yield in pre-feasibility analysis.
4. Analytical analyses of ground water conditions – complete analyses of anticipated effects of pilot-scale recharge projects, and adjust assumed aquifer properties based on monitoring of effects of pilot-scale recharge.
5. Design, construct, operate, and report on demonstration pilot projects.
6. Alternatives refinement and final feasibility recommendation – final report and recommendation for alternative(s) to be carried forward for full-scale recharge project(s), including refinement of yield and cost estimates for recharge project alternatives.

II. INTRODUCTION

The objectives of this pre-feasibility study were to 1) refine the yield and cost estimates for the "Dawson and Gothenburg Canal Ground Water Recharge" project described in the Platte River Recovery Implementation Program (Program) 2000 Reconnaissance-Level Water Action Plan (Boyle 2000); and 2) identify the most feasible ground water recharge concepts and project configurations that should be carried forward for additional study if authorized by the Program Governance Committee. The scope of work for this pre-feasibility study included development of potential recharge concepts and project locations/configurations, and estimation of yield and cost of each of the potential concepts and project configurations.

The initial Dawson and Gothenburg Canal Ground Water Recharge concept as described in the Reconnaissance-Level Water Action Plan (2000 WAP) was to recharge ground water aquifers via canal seepage from diversions to Dawson County and Gothenburg canals, which would result in recharge return flows to the Platte River for some duration after recharge. In the 2000 WAP, yield was estimated to be approximately 2,600 acre-feet per year (AFY), of which 1,800 AFY would be available to the Program and 800 AFY would be reserved by Nebraska to offset future depletions. Capital cost attributable to the Program's yield of 1,800 AFY was estimated as $13,800, and annual operation and maintenance (O&M) costs were estimated to be $10 per AF recharged. The resulting annualized costs for the Gothenburg and Dawson County canal recharge projects were $38,000 and $51,800, respectively. The 2000 WAP yield and cost estimates resulted in a First Increment unit cost of $460 per AFY for yield at the associated habitat.

After initial consideration of potential sites and yield for the range of recharge concepts, it was determined that the scope of this pre-feasibility study should be expanded beyond what was originally considered in the 2000 WAP for the Dawson and Gothenburg Canal Ground Water Recharge project as follows:

- The study area of potential recharge projects was expanded to include recharge sites along Phelps County Canal because of the proximity to the associated habitat, flexible winter operations of Phelps County Canal, and relatively high potential yield to the Platte River that could occur at sites along the canal. Additional locations were also considered that were not along an existing canal, where diversions of excess flow could be made using "headgate wells" close to the Platte River. The expanded study area is shown in **Figure 2**.
- Elements of the Nebraska "Ground Water Management" project, as described in the Reconnaissance-Level Water Action Plan, were incorporated into ground water recharge projects where possible to increase yield of recharge projects. When compared with similar types of ground water recharge projects in Colorado (e.g., Tamarack), ground water recharge in Nebraska is slightly different in that the ground water table is generally shallower and flatter with less hydraulic gradient. As a result, reliance solely on natural ground water flow to return recharged water to the Platte River may not be as successful in Nebraska as it has been in Colorado ground water recharge projects such as Tamarack.

The final analyses for this pre-feasibility study included consideration of recharge potential for sites within a study area including the area in the vicinity of Gothenburg, Dawson County, and Phelps County canals. Because of the expanded study area, the project considered for this pre-feasibility study is referred to as “Nebraska Ground Water Recharge” throughout this report.

The water supply for a Nebraska Ground Water Recharge project could be excesses to Platte River target flows and instream flows, and also could be a transfer or change of use of an existing Platte River water right (e.g., relinquishment of agricultural irrigation water). For the purposes of this pre-feasibility study, it is assumed that excesses to target flows would be used as the water supply for recharge projects. The majority of the analyses and results presented in this report would be unchanged if the water supply was instead assumed to be a transfer or change of use of an existing water right. However, there may be differences in institutional and permitting requirements depending on the actual water supply used for a recharge project.

The Nebraska “Ground Water Management” project described in the 2000 WAP included four management options to provide yield to the Platte River to reduce shortages to Program target flows:

- Option 1: Active Ground Water Pumping from High Ground Water Areas – pumping of high ground water areas with discharge to Platte River tributaries could be timed for use by the Program.
- Option 2: Passive Lowering of the Ground Water Table – farmers would be paid to dry-land farm every other year, and the reduction in surface water use would be returned to the Platte River or left in the Lake McConaughy Environmental Account (EA) for use by the Program.
- Option 3: Ground Water Irrigation – farmers would be paid to install and/or operate ground water wells in-lieu of taking delivery of surface water. Unused surface water would be made available to the Program.
- Option 4: Conjunctive Use – excess flows in Central Nebraska Public Power and Irrigation District’s (CNPPID) system could be recharged to the local ground water aquifer for subsequent irrigation use, and unused surface water would be made available to the Program.

The four ground water management options focused on potential activities to manage ground water beneath CNPPID’s system on the south side of the Platte River. A variation of Options 1, 3, and 4 could be incorporated into a ground water recharge project.

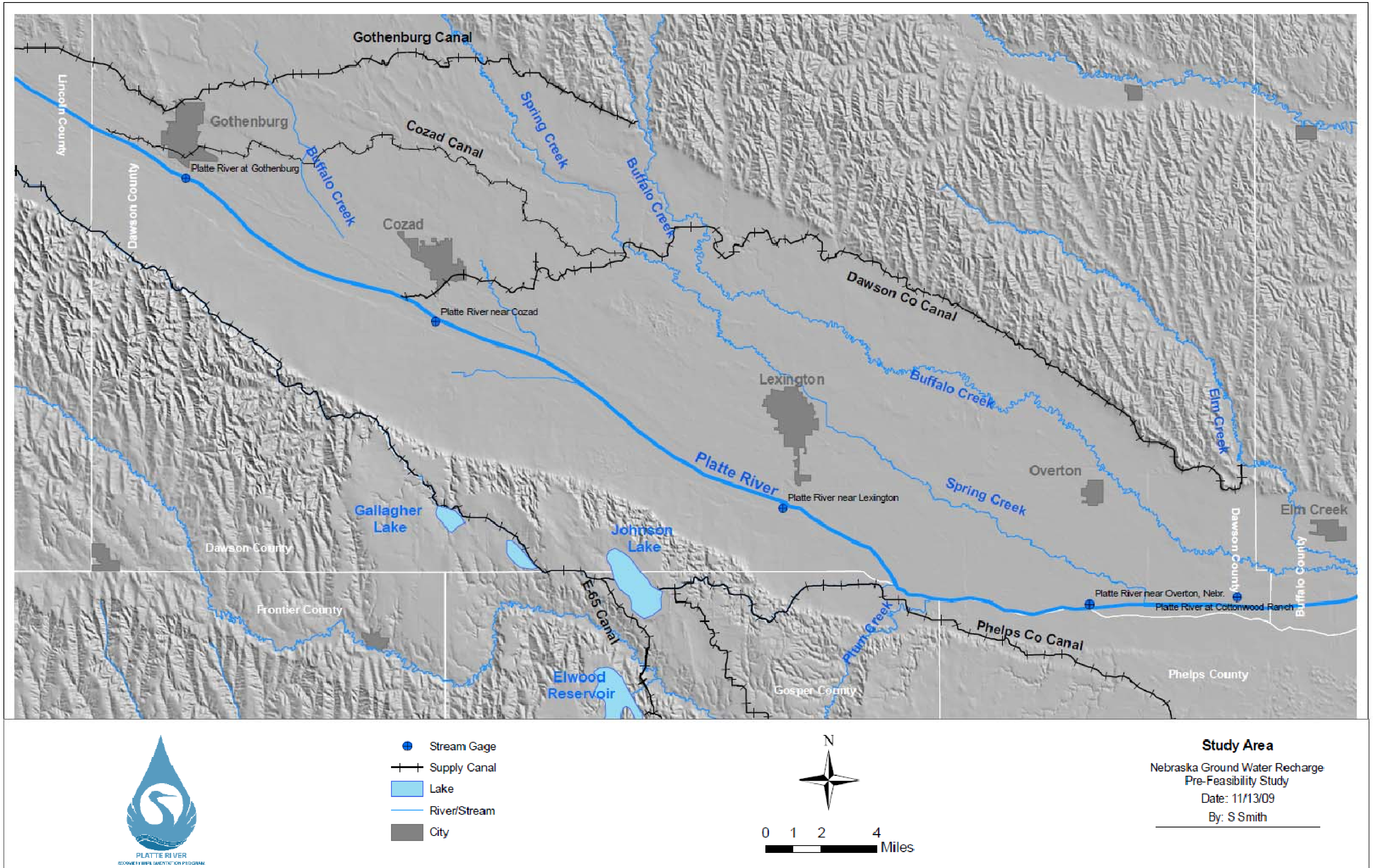

Figure 2. Nebraska Ground Water Recharge Study Area

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The work for this pre-feasibility study was completed with input from the Program's Executive Director's Office, Hahn Water Resources, LLC, and a ground water recharge technical work group composed of Water Advisory Committee members familiar with ground water related issues. Hahn Water Resources, LLC was retained by the Program as a special advisor on ground water issues and provided expert consultation on the ground water recharge concepts and the methods used to estimate cost and yield of each concept considered. Members of the ground water recharge technical work group were: Frank Kwapnioski (Nebraska Public Power District), Jeff Shafer (Nebraska Public Power District), Cory Steinke (Central Nebraska Public Power and Irrigation District), Duane Woodward (Central Platte Natural Resources District), and Jon Altenhofen (Northern Colorado Water Conservancy District). Ann Bleed and Associates, Inc. also provided input on permitting and institutional requirements in their role as special advisor to the Program on permitting issues.

The following overall general process was used to complete the analyses for this pre-feasibility study:

1. Identified the basic components of a ground water recharge project: diversion of excess streamflow, recharge of diverted water, and recovery of recharged water for project yield.
2. Identified four feasible ground water recharge concepts, consisting of various combinations of the basic components of a ground water recharge project.
3. Identified a "long list" of feasible project configurations for each of the four ground water recharge concepts.
4. Completed initial screening of the "long list" of feasible project configurations to select one configuration for detailed yield and cost analyses.
5. Conducted detailed yield and cost analyses for the "short list" of feasible project configurations, generally one configuration for each of the four ground water recharge concepts.
6. Summarized findings, and identified additional studies that could be completed to collect clarifying information to further refine ground water recharge concepts.

This report is structured to provide a description of the selection of feasible ground water recharge concepts, the "long list" of potential project configurations, the screening process used to identify a "short list" of feasible project configurations, and the results of detailed yield and cost analyses of each of configurations on the "short list."

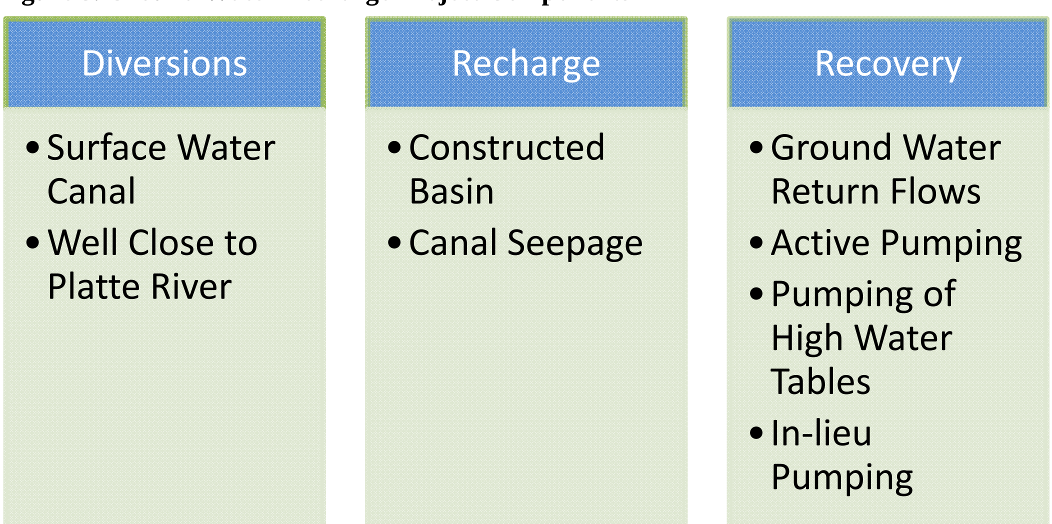
III. Ground Water Recharge Concepts and Project Configurations

The general concept applied in the formulation of ground water recharge projects is reregulation of Platte River streamflow through the diversion of excess flows to be stored in ground water aquifers and subsequently retimed to the Platte River through some combination of ground water return flows and pumping to Platte River during times of shortages to target flows. Throughout this report, the term "ground water return flows" will be used to refer to return flows to the Platte River associated with water intentionally stored in the aquifer as a result of intentional recharge achieved through canal seepage and/or at constructed ground water recharge basins.

A. Ground Water Recharge Concepts

Excess flows could be diverted using existing surface water canals, or could be diverted using alluvial wells close to the Platte River. Diverted excess flows could be recharged at a specific site to be stored in a constructed pond or basin to facilitate infiltration to ground water. Dispersed recharge could also be used, where ground water recharge would occur as a result of seepage from the canals. Recharged water would be recovered and returned to the Platte River with the objective of decreasing shortages to target flows. Recovery of recharged water could occur through any combination of natural ground water flows, pumping of recharged water to the Platte River or a tributary, and "in-lieu pumping," where irrigators would pump recharged ground water for irrigation and the Program would receive a like amount of surface water in exchange that could be used to reduce shortages to target flows. **Figure 3** provides a summary of the three components of ground water recharge projects, and the various alternatives for each of the project components. Ground water management techniques fall under the recovery project component, and could be used to increase the yield of ground water recharge projects.

Figure 3. Ground Water Recharge Project Components



Potential combinations of project components shown in **Figure 3** were identified that would result in feasible ground water recharge project concepts. The four project concepts identified as the most feasible and studied in detail for this pre-feasibility study are described in **Table 3**.

Table 3. Types of Recharge Projects Studied in Detail

Recharge Type	Means of Diversion	Means of Recharge	Means of Recovery
I	Existing canal	Constructed recharge basins close enough to the river to maximize ground water return flows in Program's First Increment, and recharge through canal seepage en route to constructed recharge basins	Ground water return flows, augmented as needed with well pumping
II	Alluvial "headgate wells"[1]	Constructed recharge basins close enough to the river to maximize ground water return flows in Program's First Increment, and/or constructed recharge basins far from the river	Ground water return flows, augmented as needed with well pumping
III	Existing canal	Constructed recharge basins far from the river, and recharge through canal seepage en route to constructed recharge basins	Active pumping and/or in-lieu pumping
IV	Existing canals (as needed)	Canal seepage (as needed)	Active pumping in areas of high ground water

B. Long List of Ground Water Recharge Project Configurations

A long list of potentially feasible ground water recharge project configurations was developed, and the array of configurations is provided in **Table 4**.

[1] Alluvial "headgate wells" are ground water wells located close enough to the river to result in nearly instantaneous depletions to surface water flow, but at least 50 feet from the river to avoid the need for a permit from the Nebraska DNR to divert surface water.

Table 4. Long List of Potentially Feasible Ground Water Recharge Project Configurations

Recharge Type[2]	Project Name	Means of Diversion	Means of Recharge	Means of Recovery
I	Phelps 9.7	Phelps Co Canal	Constructed recharge basins north of Phelps Co Canal about 9.7 miles from the J2 Return	Ground water return flows, augmented with active pumping if needed
I	Gothenburg Canal at Hwy 30	Gothenburg Canal	Constructed recharge basins at intersection of Hwy 30 and Gothenburg Canal	Ground water return flows
I	Dawson Co Canal to Berquist Lateral	Dawson Co Canal	Constructed recharge basins along Berquist Lateral	Ground water return flows
I	Phelps Co Canal south at 9.7	Phelps Co Canal	Embankment at Phelps 9.7 resulting in recharge basin using natural topography	Ground water return flows, augmented with active pumping as needed
II	Thirty Mile	Alluvial headgate wells	Constructed recharge basins at fallow lands south of the Platte River	Ground water return flows
II	Wells to existing Program Lands	Alluvial headgate wells	Constructed recharge basins on existing Program lands south of Platte River	Ground water return flows
I/II	Gothenburg Canal south of Golf Course	Gothenburg Canal	Constructed recharge basins south of Wild Horse Golf Course	Ground water return flows, augmented with active pumping
III	B1 Reservoir	Gothenburg Canal	Gothenburg Canal seepage and seepage at B1 Reservoir	Active pumping and/or in-lieu pumping
III	Elm Creek Reservoir	Dawson Co Canal	Seepage at proposed Elm Creek Reservoir	Ground water return flows, augmented with active pumping
III	Gothenburg Canal at Buffalo Creek	Gothenburg Canal	Constructed recharge basins at intersection of Gothenburg Canal and Buffalo Creek	Active pumping to Buffalo Creek
III	Gothenburg Canal at Spring Creek	Gothenburg Canal	Constructed recharge basins at intersection of Gothenburg Canal and Spring Creek	Active pumping to Spring Creek
III	Dawson Co Canal at Buffalo Creek	Dawson Co Canal	Constructed recharge basins at intersection of Dawson Co Canal and Buffalo Creek	Active pumping to Buffalo Creek
III	Dawson Co Canal near end of canal	Dawson Co Canal	Constructed recharge basins about 10 mi from end of canal	Active pumping to Buffalo Creek
IV	High ground water southwest of Overton	Dawson Co Canal (as needed)	Dawson Co Canal seepage (as needed)	Pumping of high ground water southwest of Overton delivered to Platte River via Spring Creek
IV	High ground water at Elm Creek	Dawson Co Canal (as needed)	Dawson Co Canal seepage (as needed)	Active pumping to Elm Creek

[2] Recharge type based on ground water recharge concepts described in Table 3.

IV. INITIAL SCREENING OF LONG LIST OF PROJECT CONFIGURATIONS

Initial screening of the long list of project configurations (**Table 4**) was completed to develop a short list of ground water recharge configurations for detailed yield and cost analyses. The objective of the initial screening was to identify one project configuration for each of the four ground water recharge concepts for detailed analyses. The screening was qualitatively based on the following criteria:

1. Distance to Platte River ideal for ground water return flows that would maximize project yield through the use of ground water return flows.
2. Soil type and depth to ground water that would maximize recharge rates.
3. Operational flexibility that would maximize recharge rates (e.g., maximum length of recharge season including winter months when excess flows are highest).
4. Lowest cost to yield ratio, based on qualitative assessment (e.g., given similar yield, sites with generally lower cost infrastructure were prioritized over those with more costly infrastructure such as ground water wells).

A. Distance to Platte River

Sites relying on natural return flows to the Platte River would need to be located at a distance from the Platte River and/or drains, tributaries, or wasteways to the Platte River, such that the timing of return flows to the Platte River would result in maximum project yields (i.e., return during times of shortages to target flows). Stream depletion factors (SDF) were used to determine the ideal distance to the Platte River. Concepts for development and application of SDFs are described in more detail in the section on methods and assumptions below (**Section V.F.**).

For locations extremely close to the river, return flows may arrive within days or weeks of the time of application, potentially defeating the purpose of retiming. At large distances, the return flow hydrograph becomes subdued (i.e., recharged water returns to the river at a low rate over a long period of time). Additionally, greater distances produce less yield at the Platte River during the first increment (i.e., 2007-2019) of the Program.

In light of the significant differences in the timing of return flows, SDF thresholds were established to define a range of SDF values for use in screening sites that would rely on natural retiming of return flows. The return flow hydrograph is predicted using AWAS (Alluvial Water Accounting System), a modeling tool capable of predicting the return flow hydrograph based on SDF values (IDS 2009). **Figure 4** illustrates the timing and shape of the yield hydrograph for a range of SDF values. Yield is expressed as percentage of annual diversions, calculated as follows:

1. Assumed 2,000 AF per month recharged for each September through February period (i.e., period of typically highest excesses to PRRIP target flows) for an extended period of time (48 years)
2. Modeled monthly return flows using AWAS

3. Calculated monthly yield as all return flows in the March through August period (i.e., the period of typically highest shortages to PRRIP target flows), assuming all return flows in this period could be used to reduce shortages to target flows
4. Calculated annual yield as the sum of monthly yield for a given year, divided by total annual volume recharged (i.e., 12,000 AFY, or 2,000 AF per month times 6 months)
5. Plotted annual yield in **Figure 4**, showing the first 15 years of yield as representative of what could be expected within a reasonably short period of time such as the First Increment of the Program

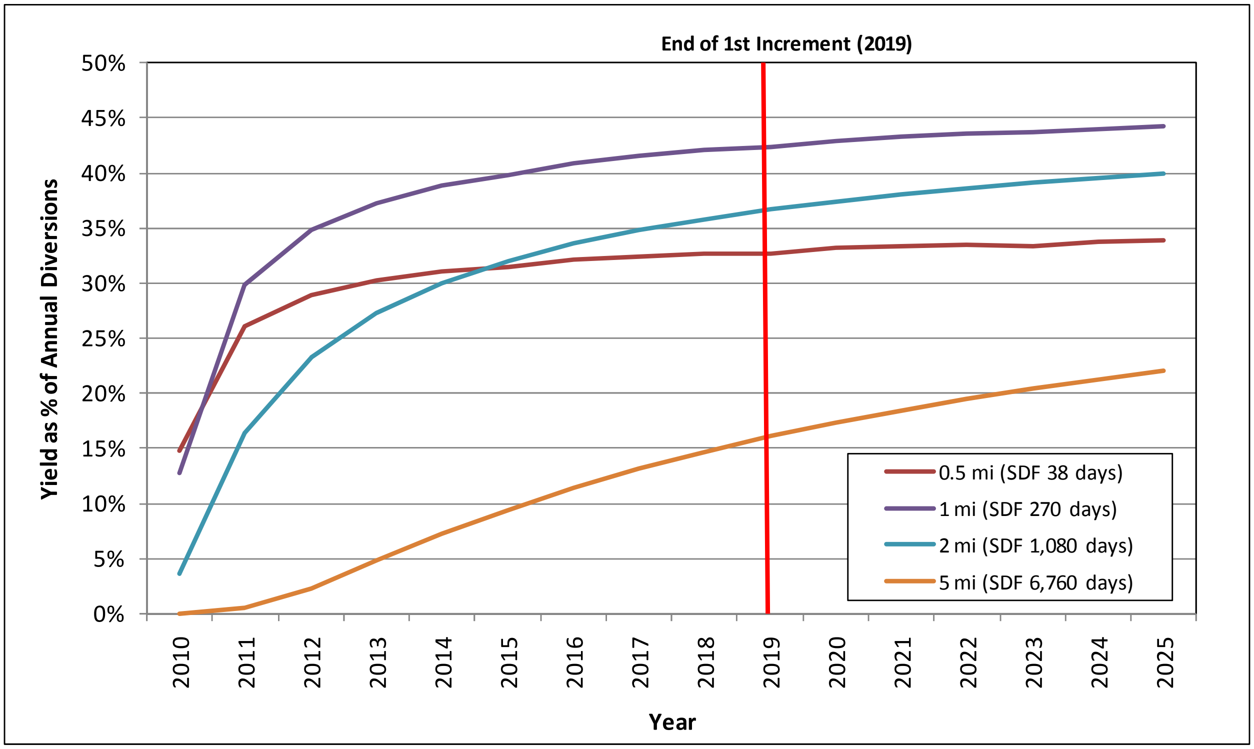


Figure 4. Mar-Aug Yield as % of Sep-Feb Diversions for Varying Distances from the Platte River

Figure 4 indicates that sites 1 mile from the river would have the highest yield as a percentage of diversions to recharge. For sites closer than 1 mile to the Platte River, a portion of recharged water would return to the river in the same month that the diversion was made. Because diversions to recharge were assumed to occur only in months of excesses to target flows (assumed to be September through February for this hypothetical example), return flows in the same month would not be credited as yield that reduces shortages to target flows. For sites further than 1 mile from the river, a substantial portion of recharged water would not return to the Platte River within a reasonably short period of time (e.g., during the First Increment of the Program). This analysis suggests that sites approximately 1 mile from the Platte River (SDF of 270 days) would be ideal for retiming of excess flows via ground water return flows. Timing of excesses and shortages to target flows are simplified for this hypothetical example as the September through February and March through August periods, respectively. Although excesses and shortages have historically occurred intermittently throughout the year, the simplifying assumptions regarding timing of shortages/excesses made for this hypothetical example are reasonable for approximating SDF thresholds for screening of potential recharge site locations. Also notable in **Figure 4** is that sites within approximately 1 mile of the Platte River come close to reaching steady-state yield by the end of the First Increment of the Program, whereas sites 2 to 5 miles from the river would be further from reaching steady-state even up to 6 years past the end of the First Increment. Assuming that scoring for any recharge project would be based on yield within the First Increment of the Program, sites within approximately 1 mile of the river would also be ideal for scoring purposes.

B. Soil Type

Sites with soils with higher recharge potential (e.g., sandy soils) would result in higher recharge than sites with finer-grained soils (e.g., silt and clay) and shallow ground water. Soil survey data from the NRCS SSURGO Database were reviewed for the study area and at specific sites considered for recharge. Soils in the study area are primarily silty loam, with smaller areas of sandy loam, loamy sand, fine sand, and loam (**Figure 5**). Generally, areas of silt loam would have the lowest potential infiltration rates (i.e., less than 1 foot per day), and areas of fine sand and sandy loam would have the highest potential infiltration rates (i.e., 2 to 3 feet per day).

C. Depth to Ground Water

Depth to ground water is a driving factor affecting the ability to infiltrate water into the aquifer for recharge. Although a depth to water of at least 10 feet would be ideal (i.e., recharge capacity would not be limited by available storage capacity in the aquifer), a minimum depth to water of 5 feet was used as a screening criterion. These depth to water criteria are based on professional judgment of available aquifer storage capacity, and also keeping in mind the potential for flooding cropland and basements with depth to water of less than 5 feet. Average depth to water for ground water monitoring wells in USGS NWIS and CPNRD well databases is shown in **Figure 6**. Depth to ground water is generally greater than 10 feet along the Gothenburg, Dawson County, and Phelps County canals, with the exception of areas close to the Platte River. Depth to water is noticeably shallow in the area southwest of Overton along Spring Creek.

D. Operational Flexibility

Sites with greater operational flexibility were prioritized over sites with less flexibility. Primary considerations for operational flexibility were for sites that could be operated for recharge throughout the winter months when streamflow generally exceeds target flows. Based on information from ground water recharge technical work group members (CNPPID 2009; NPPD 2009), the following operational flexibility considerations were used in the initial screening of the "long list" of recharge sites:

- Winter freezing issues would likely not be a problem on the Phelps County Canal for the first 9 miles because of its large and uniform cross section.
- Winter freezing issues may be a problem for the Gothenburg and Dawson County canals for the months of December through February, and additional study is needed before NPPD would commit to allowing winter recharge operations in these canals. However, winter freezing would likely not be a problem for the upper 8 miles of the Gothenburg Canal because of its uniform cross section up to that point.

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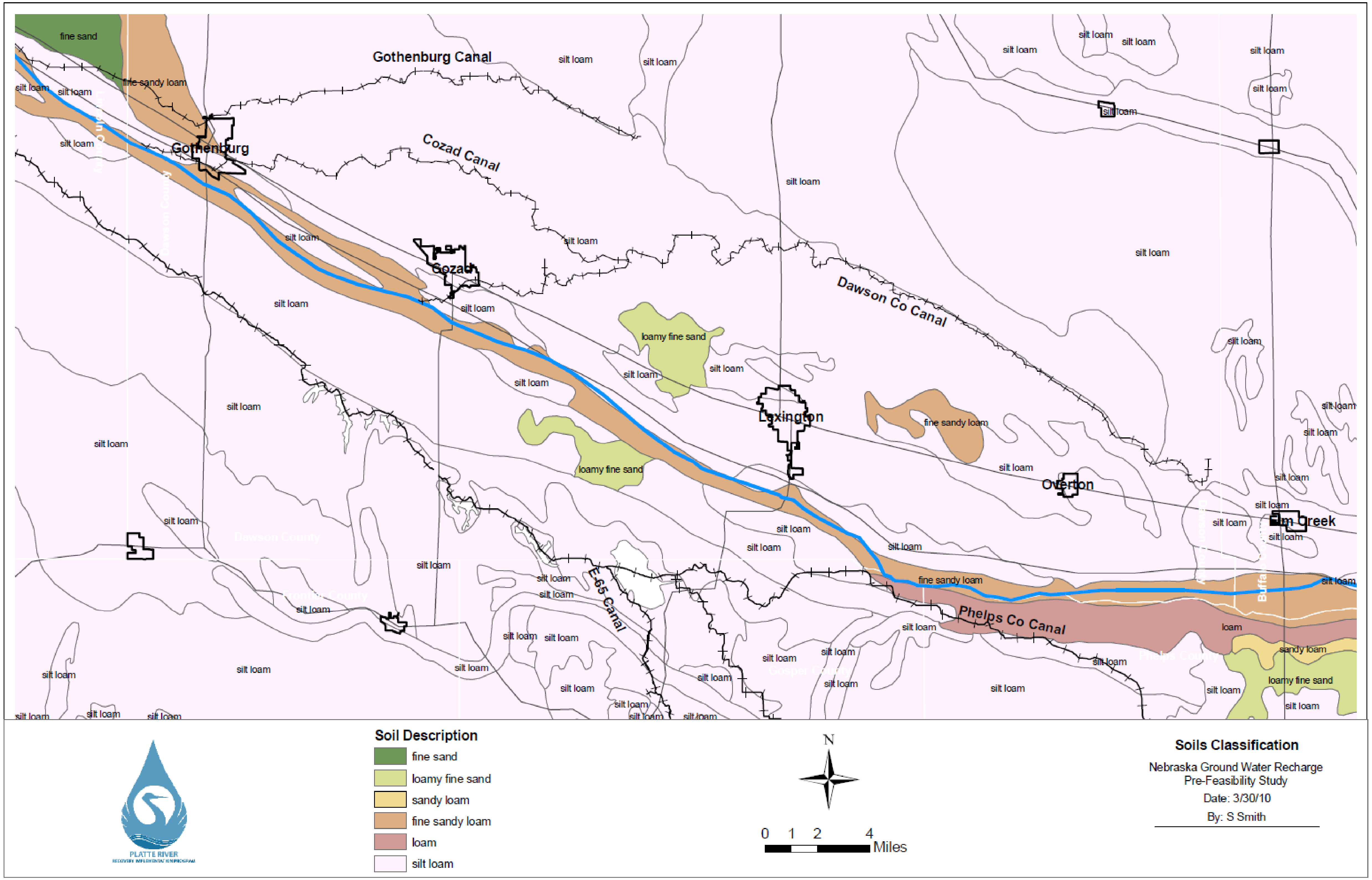

Figure 5. Soils Classification

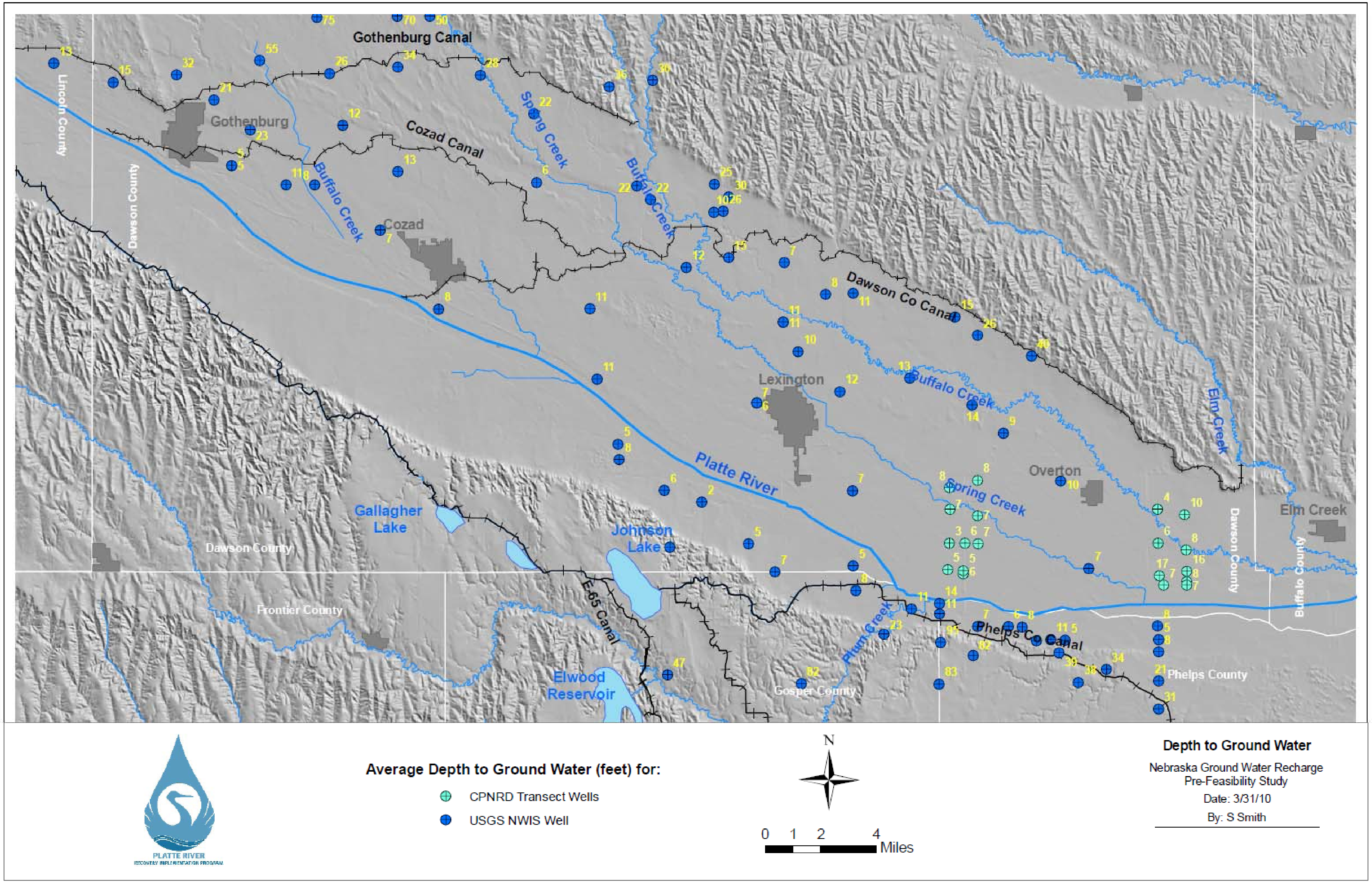

Figure 6. Depth to Ground Water

E. Cost to Yield Ratio

Sites with generally lower cost infrastructure were prioritized over those with more costly infrastructure. For screening of the initial long list of potential recharge sites, the cost to yield ratio was qualitatively analyzed based on infrastructure with generally high costs such as installation of ground water wells.

F. Screening Results – Short List of Project Configurations

A "short list" of ground water recharge project configurations was created based on the "long list" of potential project configurations and the qualitative screening criteria described above. The resulting short list of configurations analyzed in detail for this pre-feasibility study is shown in **Table 5**. The configurations were identified as representative projects that when analyzed would provide reasonable estimates of yield and cost for each of the four concepts. A fifth project configuration was added that would be a blend of the Type I and Type II ground water recharge concepts. The locations of the project configurations analyzed in detail are shown in **Figure 7**.

Table 5. Short List of Project Configurations Analyzed in Detail

Name and Type	Means of Diversion	Means of Recharge	Means of Recovery
Phelps 9.7 (I)	Phelps Co Canal	Constructed recharge basins north of Phelps Co Canal about 9.7 miles from the J2 Return, and Phelps Co. Canal seepage en route to constructed recharge basins	Ground water return flows, augmented with active pumping if needed to unnamed drainage at Phelps 9.7 location
Thirty Mile (II)	Alluvial headgate wells	Constructed recharge basins on fallow lands south of the Platte River	Ground water return flows
Gothenburg Canal south of Golf Course (I/II)	Gothenburg Canal	Constructed recharge basins south of Wild Horse Golf Course, and Gothenburg Canal seepage en route to constructed recharge basin	Ground water return flows, augmented with active pumping to Gothenburg Canal and Lake Helen hydropower tailrace as needed
B1 Reservoir (III)	Gothenburg Canal	Gothenburg Canal seepage and seepage at B1 Reservoir	Active pumping to Buffalo Creek and/or in-lieu pumping
High ground water southwest of Overton (IV)	Dawson County Canal (as needed)	Dawson County Canal seepage (as needed)	Pumping of high ground water southwest of Overton delivered to Platte River via Spring Creek

Project configurations considered but not analyzed in detail are described in **Table 6**, including a description of the technical and economical issues for each configuration that prevented these sites from being analyzed in detail.

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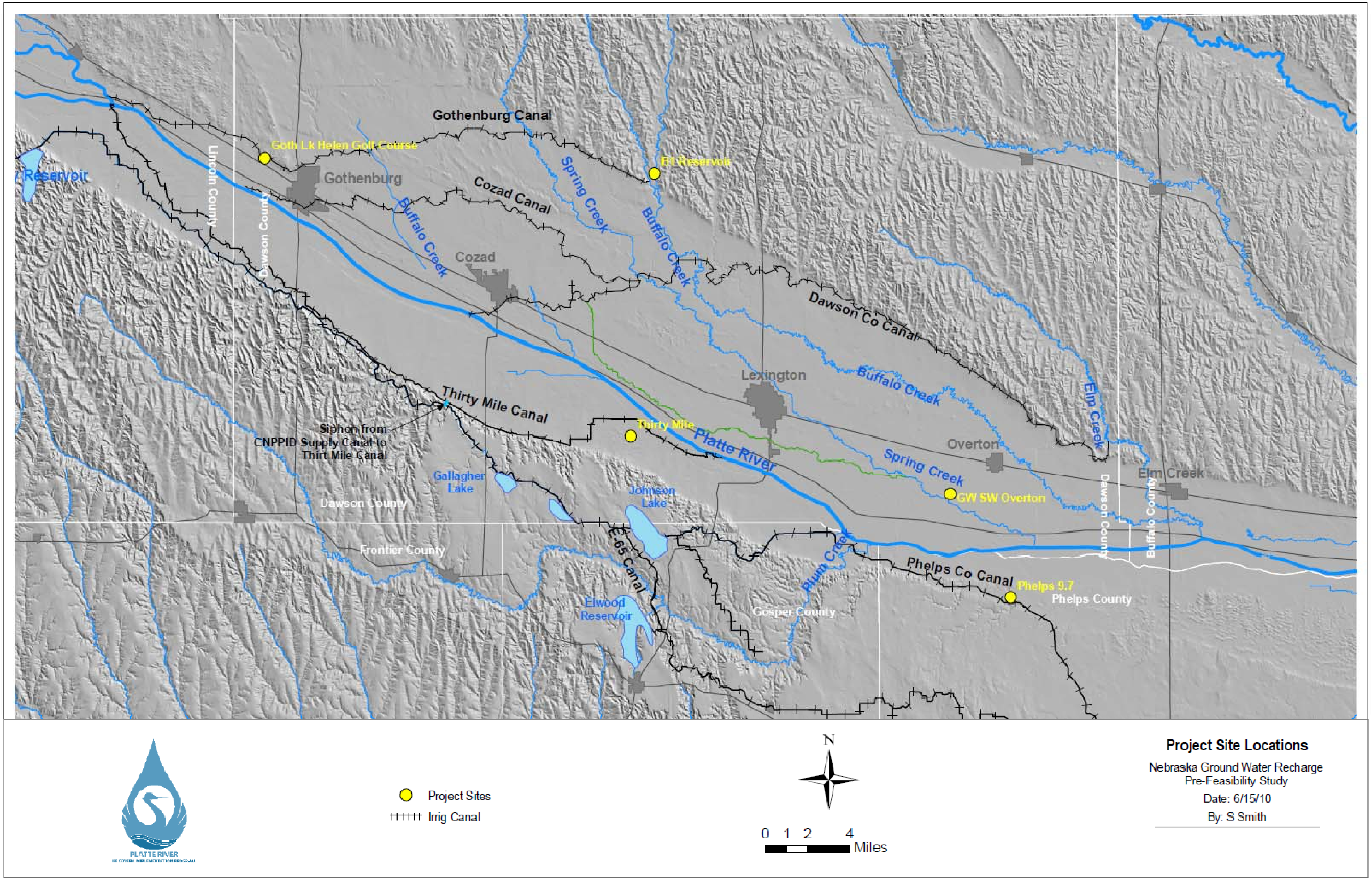

Figure 7. Site Locations for Ground Water Recharge Project Configurations Analyzed in Detail

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Table 6. Project Configurations Considered but not Analyzed in Detail

Project Name	Recharge Type	Issues Limiting Feasibility
Phelps County Canal south at 9.7	Type I	Similar attributes and benefits as the Phelps 9.7 option with constructed recharge basins analyzed in detail, but higher unit cost associated with a jurisdictional dam and modifications to an existing road bridge.
Dawson Co Canal to Berquist Lateral	Type I	Similar attributes and benefits as the Gothenburg South of Golf Course option analyzed in detail, but yield would be less because of winter icing issues[1] and higher transit losses. Site locations are approximately 0.5 miles from the river, less than the 1 mile minimum distance described above (**Figure 4**).
Gothenburg Canal at Hwy 30	Type I	Topography would limit the feasibility of gravity feeding recharge sites along the canal.
Wells to existing Program Lands	Type II	High ground water levels (i.e., less than 5 feet below ground surface) based on field observations, would limit feasibility of recharge. SDF at these sites would be approximately 29 days (calculated based on saturated thickness of 350 ft, hydraulic conductivity of 50 ft/day, specific yield of 20%, and distance to river of 0.3 mi), and return flow timing may be too fast to provide sufficient yield to address target flow shortages.
Elm Creek Reservoir	Type III	Existing high ground water levels and flooding in the town of Elm Creek would be exacerbated and would limit feasibility of ground water recharge.
Gothenburg Canal at Buffalo Creek	Type III	Similar attributes and benefits as the Gothenburg Canal to B1 Reservoir option analyzed in detail, but higher unit cost because of need to construct recharge basins. Yield would be limited because of winter icing issues[1].
Gothenburg Canal at Spring Creek	Type III	Similar attributes and benefits as the Gothenburg Canal to B1 Reservoir option analyzed in detail, but higher unit cost because of need to construct recharge basins. Yield would be limited because of winter icing issues[1].
Dawson Co Canal at Buffalo Creek	Type III	Similar attributes and benefits as the Gothenburg Canal to B1 Reservoir option analyzed in detail, but higher unit cost because of need to construct recharge basins. Yield would be limited because of winter icing issues[1].
Dawson Co Canal near end of canal	Type III	Similar attributes and benefits as the Gothenburg Canal to B1 Reservoir option analyzed in detail, but higher unit cost because of need to construct recharge basins. Yield would be limited because of winter icing issues[1].
High ground water at Elm Creek	Type IV	Similar attributes and benefits as the option of pumping high ground water southwest of Overton that was analyzed in detail, but return flows would accrue further downstream and only partially within Program's Associated Habitat area.

Notes:
[1] Based on discussion with NPPD staff, winter icing would preclude winter diversions to sites along the Gothenburg Canal at distances greater than 8 miles from the headgate, and similar distance for the Dawson County Canal (NPPD 2009). Yield for sites more than 8 miles from the canal headgate would be limited, because the majority of excesses available for diversion occur during the winter months when icing would be an issue. NPPD will be conducting future studies to determine the extent to which winter operations would be impacted by icing, and to identify ways to mitigate the effects of icing.

V. METHODS AND ASSUMPTIONS

The methods and assumptions used to complete the analyses for this pre-feasibility study are described in this section.

A. Excess Flows Available for Recharge

The water supply for this project was assumed to be Platte River flows in excess of Program target flows[3] and minimum instream flows set by Nebraska Game and Parks Commission (NGPC) and Central Platte Natural Resources District (CPNRD)[4]. Excess flows available for recharge were calculated for the period from 1947 to 1994, based on the period of record in the OPStudy Program EIS Model, (USBR and FWS 2006). Monthly *Adjusted Present Conditions with Three States Projects*[5] (Adjusted Three State) hydrology from the OPStudy Model was used. Use of the 1947 to 1994 Adjusted Three State hydrology for scoring of yield for ground water recharge projects is consistent with the approach used for other PRRIP Water Action Plan projects. Effects of variations in more recent hydrology on project yield, such as the dry period in the early 2000s, will be evaluated in future feasibility studies. Additional information on effects of various assumptions for project yield scoring will be available in a forthcoming memorandum from the PRRIP Executive Director's Office on ground water recharge project scoring.

Excess flows at Grand Island were calculated as average monthly Grand Island flows greater than the maximum of average monthly Program target flows and NGPC/CPNRD minimum instream flows. Shortages to target flows were calculated as average monthly Grand Island flows below average monthly Program target flows. Excess flows were set as the minimum of excess flows at Grand Island and flows available at the ground water recharge project diversion location. Flows available at ground water recharge project diversion locations were estimated using OPStudy flow data at the diversion location. Because the OPStudy model did not model specific canal diversions for the canals that would be used for the Nebraska ground water recharge projects, historical diversions were used to limit remaining canal capacity available to route excess flows to recharge locations. Environmental Account (EA) water and flows needed by downstream irrigators were not diverted. Excesses to target flows, based on OpStudy Adjusted Three States Hydrology for the period from 1947 to 1994, available for diversion to recharge projects at various locations are provided in **Table 7**. Excesses to target flows at Grand Island based on historical hydrology for the 1947 to 2006 period of record are also provided in **Table 7**. Although the two sets of excess flows at Grand Island are compared in **Figure 8**, it should be noted that the excesses are based on two different hydrology sets that vary both in time period (1947 to 1997 versus 1947 to 2006) and also in hydrology datasets (Adjusted Three States OpStudy hydrology versus historical hydrology). Total excess flows at Grand Island are

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[3] Weighted monthly average flows from column 8 of Appendix A-5 in the Program Document Water Plan Reference Materials.

[4] Excess flows at Grand Island are calculated as those flows in excess of the maximum of Program daily target flows and NGPC and CPNRD instream flows (Nebraska DNR, Total Platte River Instream Flow Needs for Purposes of Water Administration. 2nd Revised edition, November 7, 2007).

[5] OpStudy *Adjusted Present Conditions With Three States Projects* data for the 1947 – 1994 period was used for case-study scoring hydrology because it provides a consistent set of data with what was originally used in the Program Environmental Impact Statement (EIS) and Biological Opinion (BO). The "Adjusted" dataset was adjusted to reflect 1990's water-development conditions ("Present Conditions") and full implementation of Tamarack I, the Pathfinder Modification account, and the Environmental Account ("Three States Projects").

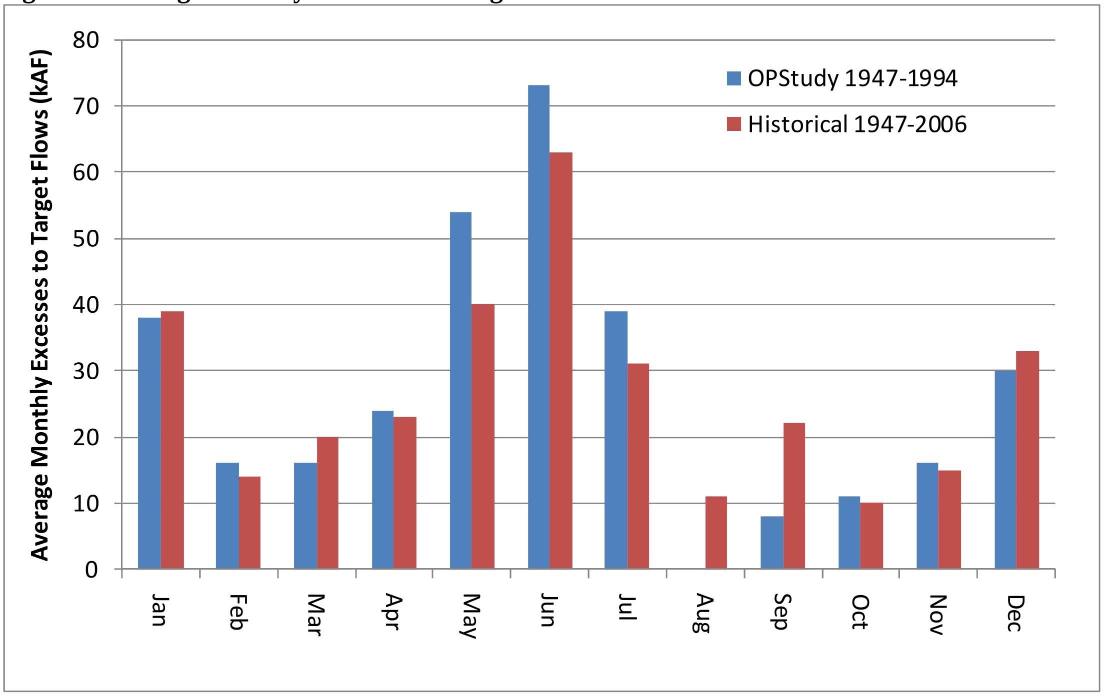
generally lower when 1947 to 2006 historical hydrology is used to determine excesses than when 1947 to 1994 OpStudy hydrology is used to determine excesses, with the largest exception occurring in August and September. It is also notable that total annual excesses to target flows available for diversion to ground water recharge projects (ranging from 183,000 to 272,000 AFY) are substantially higher than the amount of water envisioned for diversion to recharge projects (less than 10,000 AFY as limited by potential recharge rates and land area). As a result, the differences in excesses to target flows when historical or OpStudy hydrology data are used would not have an effect on the yield of ground water recharge projects.

Table 7. Average Monthly Excesses to Target Flows (kAF per month)

	Excesses to PRRIP Target Flows Based on OpStudy Hydrology (1947-1994)[1]				**Excesses to PRRIP Target Flows at Grand Island, Based on Historical Hydrology (1947-2006)[1]**
Month	**Gothenburg Canal Headgate**	**Dawson County Canal Headgate**	**Phelps County Canal Headgate**	**Grand Island**	
Jan	23	25	33	38	39
Feb	14	15	14	16	14
Mar	14	15	15	16	20
Apr	22	23	15	24	23
May	47	48	15	54	40
Jun	67	68	19	73	63
Jul	26	30	15	39	31
Aug	0	0	0	0	11
Sep	4	5	6	8	22
Oct	9	10	8	11	10
Nov	12	14	15	16	15
Dec	16	19	28	30	33
Total	254	272	183	325	321

Note:
[1] Additional information regarding methods used to calculate excesses to target flows available from PRRIP EDO in an upcoming memorandum on ground water recharge scoring.

Figure 8. Average Monthly Excesses to Target Flows at Grand Island



Excess flows available for diversion to the various recharge projects were evaluated independently of the other potential recharge projects. In other words, excess flows for one of the projects were not limited by excess flows that might be diverted for other recharge projects. Excess flows for the recharge projects were also not limited by excess flows that may be diverted for other Water Action Plan projects such as reregulating reservoirs. As WAP projects advance, additional analysis looking at the impact of multiple projects will be needed. This will likely impact the recharge project yields presented in this report. Additionally, evaluating excess flows and reductions to shortages on a daily rather than monthly basis may be useful and more closely mimic actual project operations, though the recharge project ground water model will remain monthly.

B. Canal and Constructed Recharge Basin Seepage/Recharge Rates

Two methods for recharging water were identified: recharge through canal seepage over the extent of the canal, or "dispersed recharge," and recharge at site-specific constructed ground water recharge basins. The ability to recharge water using either of the two methods is dependent on infiltration rates for soils underlying the canals and recharge sites.

Estimates for canal seepage (i.e., dispersed canal recharge) were based on permitted information where available, or physical recharge rate estimates if permitted information was not available. Physical canal seepage estimates were calculated using the following equation:

Canal seepage (cfs per mi) = Canal Wetted Perimeter (ft) x Infiltration Rate (ft/day) x 5,280 (ft/mi) / 86,400 seconds per day

Estimates for infiltration rates at constructed recharge basins were based on the Gothenburg

Synoptic Study (CPNRD and NPPD 2005), and also on discussion with the ground water recharge technical work group. Soil survey data (NRCS 2009) indicate vertical hydraulic conductivity values in the range of 0.2 to 2.00 inches per hour (0.4 to 4.0 ft/d). While the soil surveys provide information that is useful in initial screening of sites and in comparing the relative recharge attributes of different sites, the vertical hydraulic conductivity values reported in the surveys generally appear to overstate the sustained infiltration rate that might be achieved under continuous operation of a recharge facility. General experience with recharge facilities operating in similar type sediments suggests recharge rates would likely be in the range of about 1 to 3 feet per day in sandy soils, and 0.5 feet per day for finer grained soils like silty loam. A general range of infiltration rates of 1 to 3 feet per day was assumed for constructed recharge basins, with modifications on a site-by-site basis based on field observations and soil survey data.

Recharge rate estimates for this pre-feasibility study for constructed recharge basins were based on a combination of the SSURGO infiltration rates, canal seepage rate reports described above, field observations of soil type, and professional judgment.

C. Evaporation Losses

Evaporation losses from constructed recharge basins and canals were calculated using the following information from the Platte River Cooperative Hydrology Study (COHYST) Eastern Model Unit (EMU) documentation (COHYST 2007). The EMU documentation gives an average annual precipitation of 24 inches per year for the period from 1895 to 1998, and pan evaporation of 45 inches per year for the period from 1950 to 1998. Assuming a pan coefficient of 0.75 (Chow et al. 1988), lake evaporation would be 33.75 inches per year. Net evaporation, calculated as annual lake evaporation minus precipitation, would be 9.75 inches per year. Volumetric rates of evaporation were calculated as follows:

Evaporation (AFY) = net evaporation (feet/yr) * surface area (ac) * fraction of year of operation

Volumetric rates of evaporation for canal deliveries were found to be negligible relative to diversions and yield of recharge projects, and as a result were not estimated for this study. Evaporation for constructed recharge basins varied by project configuration, and was negligible for some of the configurations and not for others. As a result, evaporation at constructed recharge basins is described by project configuration in the section on Yield and Cost Estimates (**Section VII**).

D. Ground Water Levels

Depth to ground water was determined based on ground water data from the U.S. Geological Survey (USGS) Water Data for the Nation (NWIS) database, and additional data from Central Platte Natural Resources District (CPNRD) and Tri-Basin Natural Resources District (TBRNRD).

Two types of USGS NWIS data were available for wells in the study area: sites with daily data collected with automated monitoring equipment, and sites with “field water level measurements” that are measured on a less frequent basis. Both types of data were reviewed, and the representative minimum, maximum, and average depth to water was approximated through review of water level plots and statistics on the USGS NWIS website (http://waterdata.usgs.gov/nwis/gw).

Additional ground water level data were obtained from CPNRD and TBNRD for wells that are monitored on a seasonal basis by the NRDs. These wells include "transect" wells that were installed by the NRDs to monitor ground water response to changes in Platte River streamflow. The transect wells are located in lines perpendicular to the Platte River near the Elm Creek and Overton interchanges. The transect wells start close to the Platte River (i.e., about 0.5 miles from the river) and extend out to about 3 to 5 miles from the river at a spacing of about 0.5 miles.

E. Field Reconnaissance

Initial recharge concepts and project configurations were conceived for this preliminary feasibility study as described below. Field reconnaissance was completed on March 15, 2010 at each of the potential project configurations to document field conditions. The field reconnaissance team consisted of ED Office Staff, Bill Hahn of Hahn Water Resources LLC, and members of the ground water recharge technical work group. A detailed description of the activities and major findings of the field visits is provided in **Appendix A**. Field reconnaissance included observations and documentation of the following:

- Land use and type of cover
- Soil type, including hand auger samples to a depth of up to 5 feet below ground surface
- Topography, and the ability to implement recharge operations by gravity flow
- Ground water conditions, including depth to water measured in existing wells and observations of ground water levels as expressed in tributaries, canals, and drains
- Characteristics of canals and wasteways to be used in the ground water recharge projects, including general condition, geometry, bed material, and capacity

Additional field reconnaissance was completed on May 24-25, 2010 by the ED Office. Ground water percolation tests were completed at two locations to provide a field check of potential recharge rates for soils at the potential recharge sites. Percolation tests were completed at the Gothenburg Canal south of Golf Course (fine to medium Sand) and Phelps 9.7 (sandy Silt) sites, because these sites represent the range of potential soil conditions within the study area. A detailed description of the methods and results of the percolation tests is provided in **Appendix B**. Adjusted long-term sustainable infiltration rates were estimated using short-term field measured rates and a method described by Bouwer et al. (1999). **Long-term sustainable recharge rates of 2.9 feet per day and 1.1 feet per day were estimated for the Gothenburg Canal south of Golf Course and Phelps 9.7 sites, respectively.** Additional detail regarding the assumptions and methods used to estimate long-term sustainable infiltration rates is provided in **Appendix B**.

F. Calculation of Ground water return flows

The effects of a well on a nearby stream (or river) have been the subject of a number of studies including work by Theis (1941), Glover and Balmer (1954), Glover (1960) Theis and Conover

(1963), Hantush (1964, 1965), Jenkins (1967), and others. These investigators describe various solutions for evaluating the rate and volume of depletion of streamflow as a function of the rate of pumping and time. More recent studies have provided solutions for a variety on non-ideal cases, i.e. instances in which the stream/aquifer system does not fully conform to the idealized conditions required by the standard solutions. These approaches are also useful in solving the "inverse" situation, i.e. one in which water is being recharged at some location near a stream and the objective is to predict the accretions to the river as a function of the rate and timing of the recharge.

All of the solutions require that some basic physical and hydrologic properties of the stream and aquifer be specified. In the more idealized solutions, these include: distance between the well (or recharge site) and the stream, hydraulic conductivity of the aquifer, saturated thickness of the aquifer, and specific yield of the aquifer. When these properties are determined separately, and then used to compute the rate and/or volume of stream depletion by a well, the method is often referred to as the "Glover method" (Miller and Durnford 2005). Alternatively, the "effective" values for these properties may be determined using a numerical model. The benefit of using a model in this case is that the model theoretically takes into account the effects of boundaries and other non-ideal complexities (Miller and Durnford 2005) of the stream/aquifer system, and should therefore provide a better measure of the interaction between a well (or recharge site) and the stream. The factor used to evaluate this interaction is called the "Stream Depletion Factor" or SDF, and is defined as (Jenkins 1967):

$$SDF = a^2 * Sy / T,$$

where

a is the distance between the well (or recharge site) and the river in feet,
Sy is the specific yield of the aquifer in percentage,
and T is the transmissivity of the aquifer in square feet per day.

The SDF was also defined (Jenkins 1967) as the "…time from the beginning of steady pumping within which the volume of stream depletion is 28 percent of the volume pumped." SDF values can be computed through analytical solution using the equation provided above, and also can be determined using ground water models to determine the time to reach 28 percent depletion. Both methods were used in this study depending on the location of the potential recharge site as described below.

SDF values assigned to prospective recharge sites were obtained from the results of a program known as the "Cycle Well Program," which is a product of the COHYST model. The Cycle Well Program was run in conjunction with the Eastern Model Unit (EMU), also a product of COHYST (Peterson 2007). The EMU is a three-dimensional numerical model designed to simulate ground water flow in the area of the Platte River and its tributaries (Peterson 2007).

The Cycle Well Program refers to an implementation of the EMU in which pumping is modeled as constant over a 50-year period (1998 to 2048) using 1997 levels of pumping. This implementation uses one stress period having 200 time steps and constant inputs from 1997 in the original EMU.

Model runs of the EMU in combination with the Cycle Well Program were conducted by the Central Platte Natural Resources District (CPNRD). These results were made available for use in this analysis. It should be noted, however, that the Cycle Well Program work product is considered provisional and has not been formally adopted by the COHYST program.

The results of the Cycle Well Program were used to obtain a time-series of the cumulative depletions (or accretions) to the Platte River over the 50-year simulation period in response to a constant rate of pumping (or recharge). The SDF is equal to the time in days at which the cumulative depletions (or accretions) to surface water are equal to 28% of the cumulative pumping (or recharge).

The ground water aquifer in the EMU is represented using 5 layers, and the effects of modeled stresses on the aquifer represent the combined effect on the entire 5-layer system. Ground water recharge being studied for this report would only affect the top layer(s) of the aquifer. As a result, there was uncertainty whether the Cycle Well Program would be applicable for simulating SDFs for recharge that would only occur in the top layer(s) of the aquifer. CPNRD staff performed a sensitivity analysis that indicated depletions (and thus SDF values) were not sensitive to the layer simulated with the Cycle Well Program (Woodward 2009). As a result, the Cycle Well Program was determined to be accurate for use in determining SDF values for the ground water recharge study.

SDF values determined using the Cycle Well Program were checked against SDF values analytically calculated using the equation for SDF provided in the previous section. Where there were significant differences, professional judgment was used to choose the most realistic SDF value. SDF values calculated using the Cycle Well Program were generally assumed to be more accurate, except for locations near the EMU boundary where boundary effects can potentially influence the predicted SDF value.

A summary of SDF values used for each of the sites in this preliminary feasibility report including a description of which method was used to determine each value is provided in **Table 8**.

Table 8. SDF Values Used for Preliminary Feasibility Analyses

Site Name	SDF Value (Days)	Remarks on Source/Basis
Phelps 9.7 (Type I)	426	Cycle Well/EMU was used. Calculated SDF of approx. 1,400 days does not reflect the effect of intervening drains and nearby tributary streams, and therefore was not used.
Thirty Mile	182	Cycle Well/EMU was used. Calculated SDF of 558 days using T = 10,000 ft^2/d, S = 0.20 (COHYST 2006); a = 5,280 ft. (measured).
Gothenburg Canal south of Golf Course	870	Calculated, using T = 11,250 ft^2/d, S = 0.20 (COHYST 2006); a = 7,000 ft. (measured). Site located within approx. 2 cells from edge of EMU, making results susceptible to boundary conditions.
B1 Reservoir	>18,000	Return flow timing not calculated (SDF from Cycle Well > 18,000 days).
High ground water southwest of Overton	---	No recharge at this site, therefore return flow timing not calculated.

Once the SDF value has been determined for a specific location, it is possible to predict the timing and rate of changes to streamflow that would result from pumping or recharge at that location. This can be done using one of several analytical solutions, as indicated above. For this investigation, a tool known as the Alluvial Water Accounting System (AWAS) developed by the Integrated Decision Support Group at Colorado State University was used (IDS 2009). This tool incorporates several analytical solutions describing the interaction of a well or recharge pond and a stream in an alluvial system, and several types of boundary conditions that may effect this interaction. The tool provides a user interface that facilitates set-up of a particular problem, including definition of aquifer parameters, and specification of pumping and/or recharge sequences.

G. Project Yield

Yield of ground water recharge projects was based on the simulated return flows accruing to the Platte River, which would occur through a combination of ground water return flows and ground water management techniques such as active pumping to the Platte River and in-lieu pumping with agricultural irrigators. Yield was limited to the volume of monthly return flows that could be used to offset shortages to Program target flows. As a result, yield was calculated as the minimum of the monthly return flow at the associated habitat, and the monthly historical shortage at the Platte River near Grand Island gage. For project configurations where return flows would accrue to the Platte River downstream of Overton, yield was reduced to reflect the proportion of the Overton to Grand Island reach that would be affected by the return flows.

Transit losses for water conveyance to the Platte River (e.g., alternatives with active pumping to tributaries to the Platte River) were estimated based on local surface and ground water interactions for each of the water bodies used to convey water from the active pumping area to the Platte River.

Yield was adjusted to reflect transit losses between the original location of project yield and the Platte River at Grand Island streamgage. The WMC Loss Model, which was recently updated under the Water Management Study (Boyle 2008), was used to route yield to the Grand Island gage, including consideration for transit losses.

H. Cost Estimates

As a first step in developing estimates of project capital costs, a conceptual layout of facilities was developed for each of the project configurations. The types, sizes, and layout of facilities varied by site, depending on a number of factors, including anticipated deliveries, existing site conditions, the way in which the site would be operated, the means by which water would be diverted to each site, and the means by which water would be recovered at each site.

Sizing of facilities (such as diversion structures and pipelines) was generally based on an estimate of the "steady-state" recharge capacity of the site. The steady state recharge capacity of a site was estimated as follows:

Recharge Capacity (L^3/T) = Area of Recharge Basins (L^2) x Land Use Factor (%) x

Service Factor (%) x Infiltration Rate (L/T),

where, L = units of length and T = units of time. The land use factor was set at 80 percent to account for the portion of a property that would be needed for infrastructure, including roads, pipelines, etc. The service factor was intended to reflect the fact that only a portion of the full recharge area would be operational at any point in time, with some basins out of service for maintenance. A service factor of 50 percent was used for purposes of this preliminary feasibility study, and was based on professional experience.

Operation and Maintenance (O&M) costs were estimated as described for the following project elements:

- Diversion structure, canal, basin (surface water handling and recharge facilities) - the cost for operation of the surface water handling and recharge facilities was calculated as one (1) percent of the capital and land cost for constructing these facilities. This value lies within the range of percentages suggested by the Nebraska Natural Resources Development Fund Guidelines (Nebraska DNR 2000) related to irrigation facilities.
- Ground water wells – the cost for well maintenance and periodic replacement of the pump and motor. This estimate is based on engineering judgment and experience with similar projects. The connection charge for wells reflects the demand charge imposed by the electrical utility, and was obtained from published rates in the area where the projects would be built. The demand charge can be calculated based on the connected horsepower or the potential demand (in kilowatts) of the wells. The power costs reflect the kilowatt hours of consumption of electricity and the unit cost per kilowatt hour, also obtained from published rates. Neither of these (demand charge or consumption charge) reflects daily or seasonal variations in demand and use charges, nor do they reflect discounts in rates that might be obtained under various demand management options such as interruptible supply. Both estimates were calculated based on the combined pumping of all wells, rather than on a well-by-well basis.

The principal construction elements required for developing a project at one or more of the sites are listed in **Table 9**. This tabulation is not all-inclusive, but rather is intended to identify those construction elements having the greatest impact on project costs. A more complete list of construction elements would be developed during the project feasibility stage. **Table 9** also lists the unit cost for each of the construction elements. Unit costs were taken from a number of sources, including:

- Manufacturer’s list prices as posted on web sites
- Recent bid tabulations for similar elements of construction, with preference given to local projects
- Verbal estimates of cost obtained from contractors and/or vendors
- Cost data contained in reports prepared for other Program projects (Olsson Associates 2010)
- Land cost estimates provided by the ED Office
- Independent estimates based on engineering judgment and experience with similar projects

- Annual operations and maintenance costs based on guidelines from the Nebraska Resources Development Fund (2000)

Quantities of particular items (for example pipeline lengths) were estimated from the conceptual layout drawings. Lengths and dimension were approximate, and typically taken from 1:24,000 scale U.S. Geological Survey topographic maps. Elevations were also taken from these maps, and are approximate. Detailed surveying would be required as a part of feasibility-level investigations.

Project cost was amortized over the useful life of the recharge project (assumed to be 50 years) when determining the unit cost of each of the project configurations. This was considered appropriate (as opposed to amortizing over the First Increment of the Program) to facilitate a fair comparison between WAP projects with large up-front capital costs versus those with primarily long-term annual O&M costs. This method is consistent with the method used in the 2010 WAP Update (PRRIP 2010). The rate of future inflation was assumed to be 3 percent, which is also consistent with the methods used in the 2010 WAP Update.

Table 9. Cost Estimate Basis

Description	Unit	Unit Cost
Capital Costs		
Land Cost	AC	$4,000
Mobilization/Demobilization (as % of project capital cost)	%	3%
Headgate Well	LS	$75,000
Recovery Well	LS	$75,000
Canal Diversion Structure	LS	$35,000
Excavation, Recharge Basin	CY	$1.50
Discharge Structure in Basin or Canal	LS	$10,000
Stream Channel/Drain Improvements	FT	$3.00
Erosion Control/Bank Protection	YD	$30.00
SCADA, Single Facility	LS	$5,000
Piping (PVC) Furnished & Installed		
12-inch diameter	FT	$24.00
16-inch diameter	FT	$32.00
18-inch diameter	FT	$36.00
24-inch diameter	FT	$48.00
30-inch diameter	FT	$60.00
36-inch diameter	FT	$72.00
48-inch diameter	FT	$96.00
Jack and Bore, 48 in.	FT	$600
Power, Secondary Lines and Transformers	FT	$5.00
Engineering and Permitting (as % of project capital cost)	% of capital cost	10%
Contingency (as % of project capital cost)	% of capital cost	20%
Operations and Maintenance Costs		
Diversion structure, canal, basin	1.75% of Capital Cost	
Wells, Workover and Pump Replacement	YR	$1,000.00
Wells, Connection Charge	KW	$29.25
Wells, Power Cost	KwH	$0.11

VI. Institutional and Regulatory Requirements

An initial assessment of the institutional and regulatory requirements was completed for this preliminary feasibility analysis, and a more thorough understanding of the permitting requirements should be completed in future studies. Input regarding permitting requirements for ground water recharge projects was obtained from Ann Bleed and Associates (2010).

The water supply for a Nebraska Ground Water Recharge project could be from either excesses to Platte River target flows and instream flows, or from a lease of water previously used for irrigation. For the purposes of this pre-feasibility study, it is assumed that excesses to target flows would be used as the water supply for recharge projects. Alternatively, irrigation districts could transfer relinquished water to ground water recharge for Program purposes. There may be differences in institutional and permitting requirements depending on the actual water supply used for a recharge project.

For a full-scale ground water recharge project, the following permits may be needed from the Nebraska DNR:

1. Variance from stay on new surface water rights (i.e., variance from the moratorium on new surface water permits) for the diversion of flows for recharge (may not be needed if water supply would be a transfer or change of use of an existing water right).
2. Intentional recharge permit to recharge water in canals or at constructed recharge facilities.
3. Storage use permit to protect water stored in the ground water aquifer from being pumped by other users, and to protect recharged water from being diverted by other users once it reaches surface water streams.
4. Permit to levy fees or assessments for the use of recharged water.
5. For a constructed recharge basin:
    a. Permit to store water
    b. Dam safety permit, depending on the size of the recharge basin
    c. Storage use permit (could potentially be combined with storage use permit for recharged water)
6. Conduct water permit to protect water pumped and/or naturally returned to a stream from diversion by a ground water well (may not be needed if storage use permit is obtained).

A permit may be needed from the applicable Natural Resource District (NRD), and the nature of that permit would vary depending on the NRD. The construction of a new ground water well, the expansion of the number of acres irrigated, or any other change in the permit that would create an increase in consumptive use, would generally require a variance from the NRD on the moratorium on new pumping. Permitting pumping of ground water from "headgate wells," located close enough to the Platte River to effectively be considered surface water diversions, would vary depending on the distance from the wells to the Platte River. For wells within 50 feet of the Platte River, permits would be needed from both the DNR (permit to divert surface water) and from the appropriate NRD (permit to pump ground water). For wells located more than 50 feet from the Platte River, a permit from the corresponding NRD would be needed to pump ground water, but the DNR would not require a permit for a surface water diversion.

Permitting requirements for a pilot-scale demonstration project (e.g., feasibility level study demonstration project) would likely be less onerous than permitting requirements for a full-scale project as described above. The institutional and permitting issues described in **Table 10** should be addressed in order to initiate a pilot-scale demonstration project. The permitting and institutional requirements to implement a pilot-scale demonstration project could likely be achieved in approximately 6 months based on input from potential project sponsors and the Nebraska DNR.

Table 10. Permitting and Institutional Requirements for Pilot-Scale Demonstration Recharge Project

Institutional Issue	Description/Example	Likelihood of Success in 6-Month Period
1. Source of Water		
Existing water right temporary transfer	Temporary transfer of CPNRD's right associated with B1 Reservoir and Gothenburg Canal (4,000 AFY available in spring and fall)	High based on input from CPNRD
Agricultural water right – relinquishment of water used to irrigate lands under existing appropriation to an irrigation district	Willing relinquishment of water previously tied to irrigated agricultural land; irrigation district would have 5 years to assign new use, during which the right could be used for a pilot project under a lease to the Program	Medium based on input from NPPD; however, water would only be available July to August
Ground Water Pumping	Lease existing high capacity irrigation wells and pump ground water to constructed recharge basins to be subsequently returned to the aquifer through recharge	Medium based on input from CPNRD
Program EA Account	Temporary release by EA manager for pilot-scale project	Low to medium based on prior commitments for EA water and due to transit losses to recharge project
Leasing of CNPPID water rights	Temporary lease of water in CNPPID's system for release from Jeffrey and/or Johnson Lakes	Low based on CNPPID's prior commitments for delivery of water
New surface water right	Variance from stay on new surface water diversions	Very low based on typical permitting process, and limited potential to divert (junior water right)
2. Permits		
Protect recharged water	Requires intentional recharge, storage use, or conduct water permits, and change of use	Low based on typical permitting process
Do not protect recharged water	May require intentional recharge permit and change of use	High based on minimal potential for objectors
3. Project Sponsorship		
NPPD sponsorship	NPPD sponsors recharge project under Gothenburg or Dawson County Canal, including land access, and project design/operation	High based on initial feedback from NPPD
CNPPID sponsorship	CNPPID sponsors recharge project under Phelps County Canal, including land access, and project design/operation	High based on initial feedback from CNPPID
CPNRD sponsorship	CPNRD sponsors recharge project in their district involving use of ground water wells to pump water for recharge project	Medium based on initial feedback from CPNRD

Although acquiring water and permitting for a demonstration project is likely feasible in a relatively short period of time, these issues will undoubtedly be more onerous and time consuming for a full-scale recharge project. As a result, it is recommended that the Program initiate the permitting process for acquisition of a long-term water right and right to protect recharged water for full-scale projects that are considered most feasible (likely the Gothenburg Canal south of Golf Course and Phelps 9.7 projects). Preparation for the full-scale project permitting needs to be included as an initial task of any next steps for ground water recharge.

Initiation of the permitting process for a full-scale project will primarily consist of gathering information from the Nebraska DNR, applicable NRDs, and project sponsors regarding information needed for final permitting. Final permitting of a full-scale project will be dependent on which project(s) are recommended as a result of potential additional studies (e.g., potential feasibility study).

An intentional recharge permit would be the first permit that would facilitate the protection of recharged water while it is in the ground water aquifer. Under *Neb Rev. Stat.* § 46-242, water stored under a permit (e.g., intentional recharge permit) cannot be legally pumped from the aquifer without a permit from the Nebraska DNR to apply the water to beneficial use. Assuming the DNR would not grant permits for other users to pump water recharged under the Nebraska Ground Water Recharge project, this law would protect recharged water from other ground water users. The Program could seek additional protection of recharged water under *Neb Rev. Stat.* § 46-2,103, which states that any person who has obtained approval of fees or assessments under *Neb Rev. Stat.* § 46-2,101 can enjoin any person from pumping stored water if they have not agreed to pay the fee or assessment. A storage use permit could be obtained to protect intentionally stored water that returns to the Platte River.

The following two potential approaches to acquiring the necessary water rights for full-scale recharge projects are the most likely scenarios:

1. Transfer of existing water right: Irrigation districts would transfer relinquished water to intentional ground water recharge for Program purposes, and would reassign the water right to the Program through a leasing arrangement. Because a transfer of an irrigation right to another use cannot be permanent under Nebraska law, a temporary transfer would be needed and its continued renewal or extension would be subject to review and approval by the DNR.
2. Divert excesses to Platte River target flows: Program applies for new surface water diversion to divert excesses during winter months; this option would require a variance from the stay on new surface water rights, and would involve a junior priority date.

VII. Yield and Cost Estimates

The results of the yield and cost estimate analyses, and the operational assumptions made for each of the recharge configurations, are described below for each of the five feasible recharge scenarios.

A. Type I Recharge (Example Project: Phelps 9.7)

The Type I recharge concept would include diversions of excess flows for recharge using existing irrigation canals, and recharge at constructed recharge basins close to the river such that Program yield would primarily occur through the retiming of recharged water via natural ground water flow from the constructed recharge basins to the Platte River.

The Type I configuration analyzed in this study included Phelps County Canal diversions to constructed recharge basins adjacent to the canal approximately 9.7 miles downstream from where the canal splits off the J2 Return. The following assumptions were used in determining recharge potential at the Phelps 9.7 site:

- Recharge operations were assumed to occur from September through May to avoid conflicts with CNPPID’s irrigation operations.
- Two recharge basins would be located on a total area of 80 acres. Total recharge area and active recharge area would be 64 acres and 32 acres, respectively, allowing for 20 percent of the total area set aside for interior infrastructure (e.g., access roads) and 50 percent of the total area assumed to be out of operation at any given time for maintenance.
- Evaporation losses for recharge operations were estimated to be 20 AF over 9 months of recharge operations. Because evaporative losses were less than 1 percent of total diversions, evaporation was considered to be negligible and was not factored into estimates of diversions or yield. Evaporation losses were calculated assuming an active recharge surface area of 32 acres, and a net effective evaporation rate of 0.61 ft over 9 months of recharge operations. The rate of evaporation was based on average pan evaporation of 45 inches per year and average annual precipitation of 24 inches per year from the Eastern Model Unit documentation (COHST 2007), and an assumed pan evaporation coefficient of 0.75.
- Yield from recharged water would occur as a result of ground water return flows, calculated using the SDF method described above and an SDF of 426 days as determined with the COHYST Cycle Well model.
- Yield could be increased by including recovery wells that would pump recharged water back to the Platte River via the unnamed drainage at the Phelps 9.7 location. Maximum yield from this active pumping would occur if the wells were operated on a daily basis to most closely match shortages to target flows.
- Approximately 1,000 AF of water would need to be diverted to the Phelps County Canal for the initial fill of the 9.7 miles of canal upstream of the constructed recharge basins. This initial fill would provide enough head in the canal to facilitate the use of the existing canal turnout used to irrigate the fields where constructed recharge basins would be located. Additional water may need to be diverted to the canal to maintain adequate

operating head. Any portion of additional water needed to maintain adequate head for diversions from the canal that could not be recharged through canal seepage or in constructed recharge basins would be returned to the Platte River via the Phelps 9.7 return and the unnamed drainage back to the Platte River labeled as "Improved Stream Channel" in **Figure 9**. Any additional water that is cycled back to the Platte River would not be credited towards yield of the recharge project.

- Total canal seepage losses from the J2 Return to the Phelps 9.7 constructed recharge basins would be 20 cfs (CNPPID 2009), or about 2 cfs per mile. Seepage losses were assumed to return to the Platte River via natural ground water recharge. Yield from seepage losses was calculated with the same process used to determine natural recharge from return flows associated with recharge at Phelps 9.7 constructed recharge basins. An SDF of 426 days was assumed to apply to canal seepage losses, based on the SDF for the recharge basins. Although the COHYST Cycle Well model predicted an SDF of 365 days for the Phelps County Canal midway between the J2 Return and the 9.7 location, the effect of the small difference in SDF was assumed to be insignificant in the calculation of total return flows.
- Infiltration rate of 1.0 foot per day based on percolation tests completed during field reconnaissance (see **Appendix B**).
- Approximately 10,000 feet of the unnamed drainage at the Phelps 9.7 location from the canal to the Platte River would be improved to provide the ability to cycle water through the Phelps County Canal to minimize the potential for icing on the canal during winter operations. Water cycled through the canal and back to the Platte River via the unnamed drainage would primarily be cycled through the canal in times when the basins was not able to accept additional water (e.g., recharge basins are full or under maintenance). This additional water would not be diverted to the constructed recharge basins, but would keep the Phelps County Canal ice shelf high enough to minimize operational challenges from icing.
- Yield at Grand Island was discounted to reflect the portion of the Overton to Grand Island reach that return flows would affect (i.e., yield was multiplied by 98 percent to determine the portion of yield that could be credited to the project's score).

The Phelps 9.7 recharge configuration layout is shown in **Figure 9**. Recharge capacity for the Phelps 9.7 site is summarized in **Table 11**. The resulting yield and project efficiencies (i.e., yield as percent of total diversion) are shown in **Table 12**. In addition to the yield shown in the tables, approximately 3,070 AFY of return flows would not reduce shortages to target flows because of the timing of the return flows during periods of excesses to target flows, and because of the discounted yield to reflect the portion of the Overton to Grand Island reach affected by return flows. These additional return flows could potentially be captured by other Program water projects (e.g., reregulating storage) and used to reduce shortages to target flows at a later time, or used by Nebraska to offset post-1997 depletions as part of their PRRIP depletions plan. Average monthly diversions, yield at Grand Island, and return flows at Grand Island not credited to yield are provided in **Appendix C**.

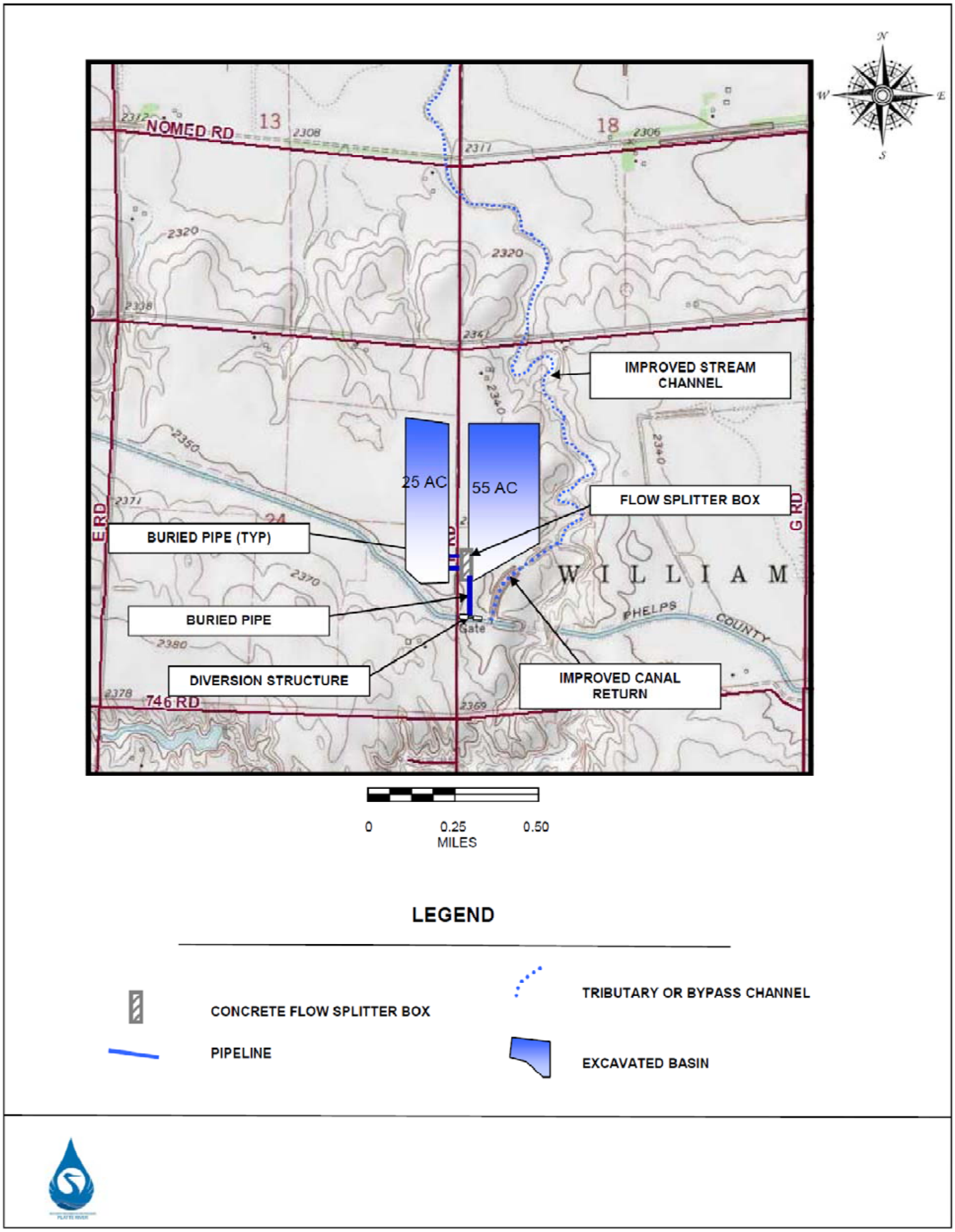


Figure 9. Phelps 9.7 Layout

Table 11. Phelps 9.7 Type I Physical Recharge Characteristics

Canal Seepage	40 AFD (20 cfs)
Number of Basins	2
Total Area	80 acres
Active Recharge Area[1]	32 acres
Infiltration Rate	1.0 foot per day
Recharge Basin Rate of Recharge	32 AFD (16 cfs)
Total Recharge Capacity[2]	**72 AFD (36 cfs)**

Notes:
[1] Active recharge area calculated as total area less 20 percent for infrastructure requirements and an additional 50 percent out of operation for maintenance/cleaning.
[2] Total recharge capacity calculated as canal seepage plus rate of recharge at constructed recharge basins.

Table 12. Yield Estimates for Phelps 9.7 Associated with Canal Seepage and Recharge Basins

	Yield[1] and Efficiency[2] by Location (AFY)	
Diversions (AFY)	**Project Location**	**Grand Island**
8,600	3,995 (46%)	3,321 (39%)

Notes:
[1] Yield defined as the volume of return flows that can be credited to reducing target flow shortages, and reduced to reflect the portion of the Overton to Grand Island reach that would be affected by the return flows.
[2] Efficiency calculated as yield divided by diversions.

Cost estimates for the Phelps 9.7 Type I configuration were developed assuming that the yield will come from ground water return flows. Capital and annual O&M cost estimates for the Phelps 9.7 Type I configuration are provided in **Table 13** and **Table 14**, respectively.

Table 13. Phelps 9.7 Capital Cost Estimates

Description	**Approximate Quantity**	**Unit**	**Unit Cost**	**Extended Cost**
Mobilization/Demobilization	1	LS	$43,000	$43,000
Basin Excavation	206,507	YD	$1.50	$310,000
Delivery Pipe (36” diameter)	200	Ft	$72	$14,000
Diversion Structure	1	LS	$35,000	$35,000
Canal Wasteway Improvements	1	LS	$25,000	$25,000
SCADA	1	LS	$5,000	$5,000
Rip-rap Bank Protection	500	YD	$30	$15,000
Stream Improvement	10,000	Ft	$3	$30,000
Concrete Splitter Box	1	LS	$20,000	$20,000
Pipe for Road Crossing (2 @ 36” diameter)	160	Ft	$140	$22,000
Discharge Structure at Basin	2	LS	$10,000	$20,000
Land for Recharge Basins	80	AC	$4,000	$320,000
Sub-Total				$840,000
Engineering & Permitting (10%)				$84,000
Contingency (20%)				$168,000
Total Capital Cost				**$1,092,000**

Table 14. Annual O&M Costs for the Phelps 9.7 Type I Configuration

Description	Approximate Quantity	Unit	Unit Cost	Extended Cost
Annual O&M	$772,000[1]	% capital	1.75%	$13,510
Total Annual O&M Cost				**$13,510**

Notes:
[1] Annual O&M based on total capital cost minus land costs

Based on capital cost of $1.1 M and annual O&M costs of $14,000, and assuming a 50 year project life with a 3 percent discount rate, the total unit cost for the Phelps 9.7 Type I recharge project would be approximately $17 per acre-foot per year based on project yield (i.e., reductions to target flow shortages) at Grand Island.

B. Type II Recharge (Example Project: Thirty Mile)

The Type II recharge concept would include diversions of excess flows for recharge using "headgate wells," which are ground water wells close to the Platte River such that pumping of the wells would be essentially equivalent to diverting directly from the river (i.e., depletions to the river would occur within the same month as well pumping). Excess flows would be pumped via pipeline from headgate wells to constructed recharge basins close to the Platte River such that Program yield would primarily occur through the retiming of recharged water via natural ground water flow from the constructed recharge basins to the river. There are two potential benefits for this type of recharge configuration:

1. Recharge sites do not need to be located along an existing canal, because headgate wells can be located anywhere along the Platte River.
2. Ground water diverted using headgate wells would be warmer than surface water diverted using existing canals, which would help minimize potential icing issues during winter operations.
3. Potentially could use the headgate wells to recapture ground water return flows that would otherwise return to the Platte River during times of excesses to target flows (i.e., would not otherwise be counted towards project yield).

The Type II configuration analyzed in this study included diversion of excess streamflow using "headgate wells" located on the south side of the Platte River approximately two-thirds of the way from Cozad to Lexington. The wells would be located in Township 9 north, Range 22 west, Section 8. Diversions would be conveyed to constructed recharge basins in the southeast quarter of Township 9 north, Range 22 west, Section 7. Because of the site's proximity to Thirty Mile Road, this site will be referred to as the "Thirty Mile site." A general layout of the Thirty Mile site is provided in **Figure 10**. The following assumptions were used in determining recharge potential at the Thirty Mile site:

- Diversion and recharge operations were assumed to occur from September through May to avoid conflicts with irrigation demands on the Platte River.
- Sixteen (16) headgate wells would be installed to divert excess flows; each well would have a pumping capacity of 1,400 gallons per minute (gpm). Total pumping capacity

would be 17,920 gpm (79 AFD) at any given time, assuming 20 percent of the wells would be out of service or off for maintenance.

- Excess flows available for diversion to the Thirty Mile headgate wells were assumed to be equal to excess flows available at the Dawson County Canal headgate. This is likely a conservative estimate of excess flows available for diversion, because there are no significant diversions between the Dawson County Canal and the location of the Thirty Mile headgate wells.
- One recharge basin would be located on a total area of 96 acres, with a total active recharge area of 39 acres, allowing for 20 percent of the total area set aside for interior infrastructure (e.g., access roads) and 50 percent of the total area assumed to be out of operation at any given time for maintenance.
- Evaporation losses for recharge operations were estimated to be 59 AF over 9 months of recharge operations. Because evaporative losses were less than 1 percent of total diversions, evaporation was considered to be negligible and was not factored into estimates of diversions or yield. Evaporation losses were calculated assuming a recharge surface area of 96 acres, a net effective evaporation rate of 0.61 ft over 9 months of recharge operations. The rate of evaporation was based on average pan evaporation of 45 inches per year and average annual precipitation of 24 inches per year from the Eastern Model Unit documentation (COHST 2007), and an assumed pan evaporation coefficient of 0.75.
- Yield from recharged water would occur as a result of ground water return flows, calculated using the SDF method described above and an SDF of 182 days as determined with the COHYST Cycle Well model.
- Infiltration rate of 2.0 feet per day based on loamy fine sand as indicated by the soil survey data and shown in **Figure 5**.

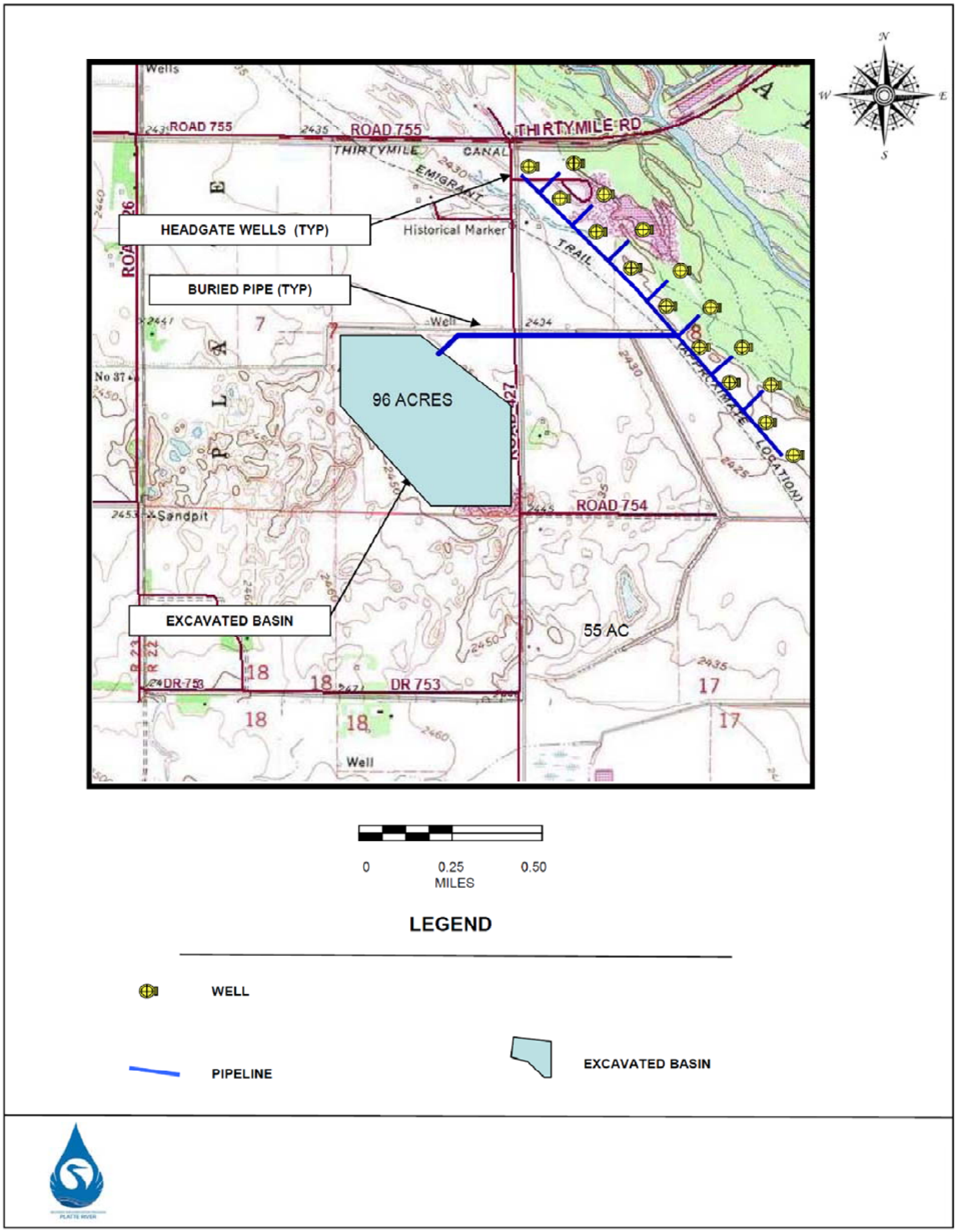


Figure 10. Thirty Mile Site Layout

Recharge capacity for the Thirty-Mile site is summarized in **Table 15**. The resulting yield and project efficiencies (i.e., yield as percent of total diversion) are shown in **Table 16**. In addition to the yield shown in the table, approximately 3,760 AFY of return flows would not reduce shortages to target flows because of the timing of the return flows during periods of excesses to target flows. These additional return flows could potentially be captured by headgate wells and returned to recharge basins, or captured other Program water projects (e.g., reregulating storage) and used to reduce shortages to target flows at a later time, or used by Nebraska to offset post-1997 depletions as part of their PRRIP depletions plan. Average monthly diversions, yield at Grand Island, and return flows at Grand Island not credited to yield are provided in **Appendix C**.

Table 15. Thirty Mile Type II Physical Recharge Characteristics

Number of Basins	1
Total Area	96 acres
Active Recharge Area[1]	39 acres
Infiltration Rate	2.0 foot per day
Recharge Capacity	**78 AFD (39 cfs)**

Notes:
[1] Active recharge area calculated as total area less 20 percent for infrastructure requirements and an additional 50 percent out of operation for maintenance/cleaning.

Table 16. Yield Estimates for Thirty-Mile Type II Site

	Yield[1] and Efficiency[2] by Location (AFY)	
Diversions (AFY)	**Project Location**	**Grand Island**
9,289	4,185 (45%)	3,490 (38%)

Notes:
[1] Yield defined as the volume of return flows that can be credited to reducing target flow shortages.
[2] Efficiency calculated as yield divided by diversions.

Cost estimates for the Thirty-Mile Type II configuration were developed assuming that the yield will come from ground water return flows. Capital and annual O&M cost estimates for the Thirty Mile Type II configuration are provided in **Table 17** and **Table 18**, respectively.

Table 17. Thirty Mile Site Capital Cost Estimates

Description	Approximate Quantity	Unit	Unit Cost	Extended Cost
Mobilization/Demobilization	1	LS	$86,000	$86,000
Basin Excavation	248,453	YD	$1.50	$373,000
Rip-rap Bank Protection	500	YD	$30	$15,000
Discharge Structure at Basin	1	LS	$10,000	$10,000
Land for Recharge Basins	96	AC	$4,000	$384,000
Headgate Wells	16	LS	$75,000	$1,200,000
SCADA	17	LS	$5,000	$85,000
PVC Pipe: 16-inch	3,500	Ft	$32	$112,000
PVC Pipe: 24-inch	1,750	Ft	$48	$84,000
PVC Pipe: 36-inch	2,100	Ft	$72	$151,000
PVC Pipe: 48-inch	4,220	Ft	$96	$405,000
Power Line and Transformers	8,050	Ft	$5	$40,000
Sub-Total				$2,945,000
Engineering & Permitting (10%)				$295,000
Contingency (20%)				$589,000
Total Capital Cost				**$3,829,000**

Table 18. Annual O&M Costs for Thirty Mile Type II Configuration

Description	Approximate Quantity	Unit	Unit Cost	Extended Cost
Annual O&M (except for wells)	$2,245,000[1]	% capital	1.75%	$39,288
Annual O&M for Wells	16	LS	$1,000	$16,000
Power Costs				
Demand Charge	137	KW	$29.25	$4,000
Pumping Cost	6,545	Hr	$16	$101,509
Total Annual O&M Cost				**$160,796**

Notes:
[1] Annual O&M (except for wells) based on total capital cost minus capital cost of wells and land costs

Based on capital cost of $3.83 M and annual O&M costs of $161,000, and assuming a 50 year project life with a 3 percent discount rate, the total unit cost for the Thirty Mile Type II recharge project would be approximately $89 per acre-foot per year based on project yield (i.e., reductions to target flow shortages) at Grand Island.

An alternative project configuration for the Thirty Mile site would utilize Thirty Mile Canal (location shown in **Figure 7** and **Figure 10**) deliveries to the constructed recharge basin shown in **Figure 10**. This alternative would have lower capital and operational costs than using headgate wells to deliver water to the recharge basin. However, the benefits of using headgate wells would not be realized (warmer water to minimize freezing issues, and the potential to use headgate wells to capture return flows that would otherwise return to the Platte River during times of excesses to target flows). Canal deliveries could be made using water from CNPPID's Supply Canal, diverted through the siphon connecting the Supply Canal to Thirty Mile Canal (**Figure 7**). The siphon is approximately 10 miles west of the Thirty Mile recharge site. Assuming transit loss of 1 cfs per mile, 49 cfs total would need to be diverted from CNPPID's

Supply Canal to Thirty Mile Canal (39 cfs for recharge at the constructed recharge basins, plus 10 cfs transit loss/intentional recharge along the Thirty Mile Canal). Costs for the alternative of using Thirty Mile Canal for delivery of water in lieu of headgate wells would include capital cost of approximately $1.2 million and annual costs of approximately $14,000 (not including power interference costs, which have not been estimated for this pre-feasibility analysis). Based on these initial and annual costs, assuming a 50 year project life and 3 percent discount rate, the total unit cost for the alternative of using Thirty Mile Canal in lieu of headgate wells would be approximately $17 per acre-foot per year based on project yield at Grand Island (compared to $91 per acre-foot per year for the alternative of using headgate wells). While use of canals to deliver water to the constructed recharge basin would have a lower cost relative to the use of headgate wells, the following are disadvantages of using Thirty Mile Canal for delivering water to be recharged:

- Power interference costs would exist if water is diverted from CNPPID's Supply Canal for ground water recharge (diversion would be downstream of the Jeffrey Reservoir hydro-facility, but upstream of the J1 and J2 hydro-facilities).
- The majority of Thirty Mile Canal between the siphon and the proposed recharge site is approximately 4 miles from the Platte River, with an SDF value of about 1,190 days as calculated with Cycle Well. Because of the large distance between the canal and the Platte River, most of the 10 cfs of transit loss would not return to the Platte River within a reasonably short time period (e.g., the First Increment of the Program) as discussed in **Section IV.A**.
- Winter freezing would be more likely for the scenario with canal deliveries compared to that for the scenario using headgate wells.
- Upgrades may be needed on the siphon between CNPPID's Supply Canal and Thirty Mile Canal, which could add substantial cost to the initial cost estimate described above.
- It is unknown whether the Thirty Mile Canal Company would be willing project sponsors for a recharge project as envisioned for this scenario.

C. Type I/II Recharge (Example Project: Gothenburg Canal South of Golf Course)

A Type I and Type II combination project configuration was analyzed to assess the advantages of combining both surface and ground water diversions of excess streamflow. This configuration could be operated solely as a Type I recharge concept (i.e., diversions using existing canals), or surface water diversions could be supplemented with diversions from "headgate wells." The Type I/II recharge project configuration was analyzed under the following scenarios (analyzing the Type I and Type II configuration for both of the scenarios described below provides the ability to compare the effect of adding headgate well diversions on project yield and cost):

1. Diversions of excess flows using the Gothenburg Canal, conveyed to a constructed recharge pond at a site south of the Wild Horse Golf Course west of the City of Gothenburg. Yield to the Program would be achieved through ground water return flows from the recharge site to the Platte River. Additional water could be cycled through a loop using the Gothenburg Canal and an improved Lake Helen hydropower tailrace, minimizing icing issues during winter operations.
2. Diversions of excess flows using both Gothenburg Canal and new "headgate wells" located near the Gothenburg Canal headgate, which would pump warm ground water into

the Gothenburg Canal. The combined surface and ground water diversion would be conveyed in the Gothenburg Canal to a constructed pond at a site south of the Wild Horse Golf Course west of the City of Gothenburg. Yield to the Program would be achieved through ground water return flows from the recharge site to the Platte River.

Recharge operations would be identical for both of the Type I/II configuration scenarios. Excess flows would be recharged at a constructed recharge basin approximately 2 miles northwest of the City of Gothenburg and one-quarter mile south of the Wild Horse Golf Course, referred to as the "Gothenburg Canal south of Golf Course" site throughout this report. A layout of the recharge facilities for the site is provided in **Figure 11**.

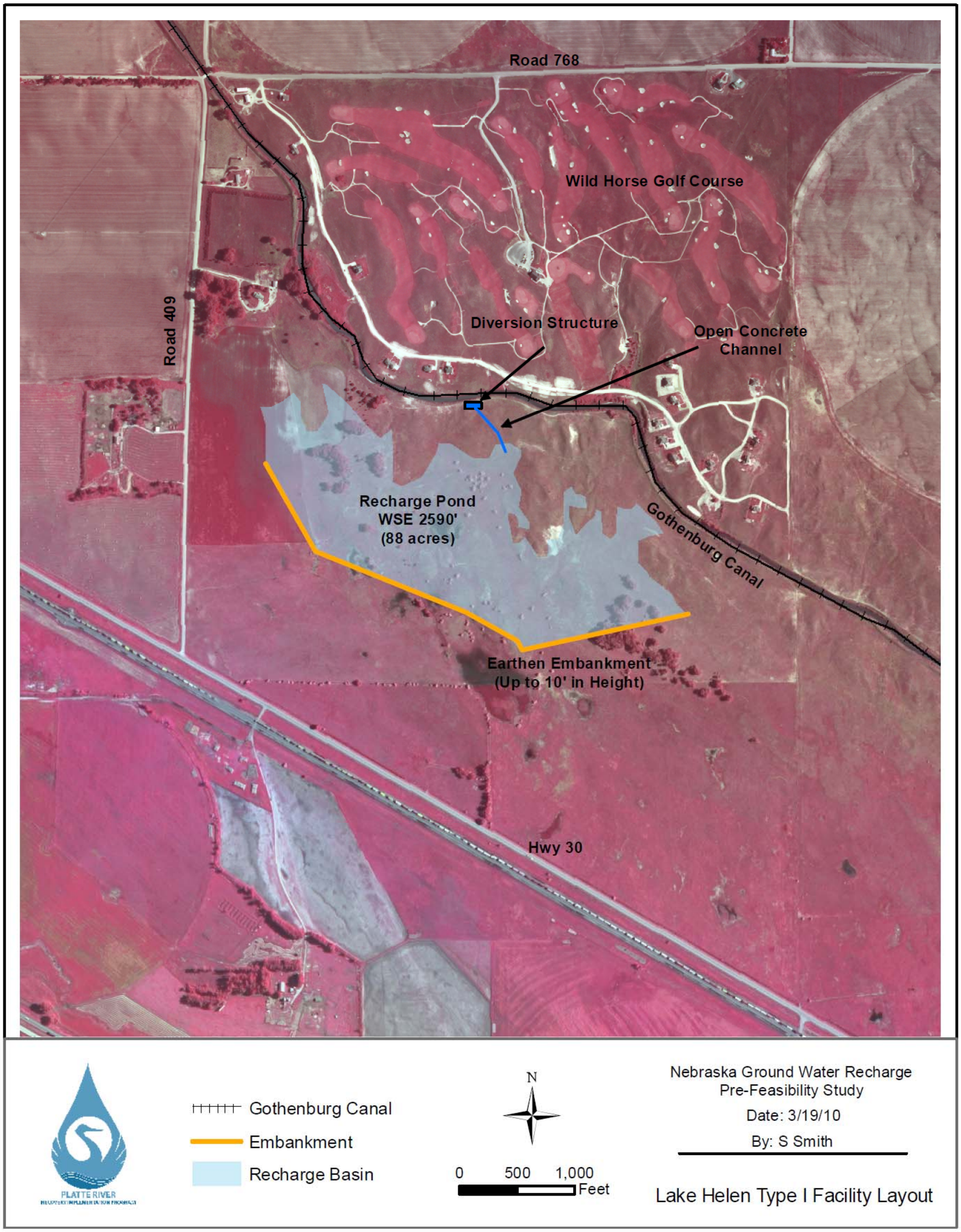


Figure 11. Site Layout for Gothenburg South of Golf Course

The following assumptions were used in determining recharge potential for the Gothenburg Canal south of Golf Course configuration:

- Recharge operations were assumed to occur from September through May, assuming use of excesses to target flows, to avoid conflicts with NPPD's irrigation operations; however, if water supply was irrigation water leased from NPPD, operating season may be limited to July to August.
- One recharge basin would be located on a total area of 88 acres, with a total active recharge area of 35 acres, allowing for 20 percent of the total area set aside for interior infrastructure (e.g., access roads) and 50 percent of the total area assumed to be out of operation at any given time for maintenance.
- Evaporation losses for recharge operations were estimated to be 54 AF over 9 months of recharge operations. Because evaporative losses were less than 1 percent of total diversions, evaporation was considered to be negligible and was not factored into estimates of diversions or yield. Evaporation losses were calculated assuming a recharge surface area of 88 acres, a net effective evaporation rate of 0.61 ft over 9 months of recharge operations. The rate of evaporation was based on average pan evaporation of 45 inches per year and average annual precipitation of 24 inches per year from the Eastern Model Unit documentation (COHST 2007), and an assumed pan evaporation coefficient of 0.75.Yield from recharged water would occur as a result of ground water return flows, calculated using the SDF method described above and an SDF of 870 days as calculated with the analytical equation for SDF. The analytical approach for calculating the SDF was used for this site, because the site is located within one-half mile of the western boundary of the COHYST model. As described in **Section V.G**, SDF values calculated analytically are likely more accurate than those from the COHYST Cycle Well model for sites close to the model boundary because of the boundary effects of the model.
- Total canal seepage losses from the Gothenburg Canal headgate to the constructed recharge basin would be approximately 12 percent of the diversion at the headgate, based on a weighted average unit transit loss of approximately 1.4 percent per mile (CPNRD and NPPD 2005). Yield from seepage losses was calculated with the same process used to determine natural recharge from return flows associated with recharge at the constructed recharge basins. Distance from the canal to the Platte River at the halfway point between the headgate and the recharge basins was approximately 6,400 feet, which was similar to distance between the recharge basins and the Platte River (7,000 feet). As a result, the same SDF (870 days) was used to calculate return flows associated with both canal seepage and recharge at the constructed basins.
- Yield could be increased by including recovery wells that would pump recharged water back to the Platte River via the Gothenburg Canal and Lake Helen hydropower tailrace. Maximum yield from this active pumping would occur if the wells were operated on a daily basis to most closely match shortages to target flows.
- Infiltration rate of 2.0 feet per day at constructed recharge basins based on fine sandy loam soil samples collected during field reconnaissance, and verified with soil survey data as shown in **Figure 5**.
- Approximately 12,200 feet of a drain south of the site would be improved to provide additional capacity that may be needed to convey ground water seepage from recharge

operations. Flow in the drain may increase as a result of increased ground water levels caused by recharge operations at the site.

- Bank protection would be added to approximately one-quarter mile of the Lake Helen hydropower tailrace downstream of Lake Helen to minimize potential erosion from cycling of water through the Gothenburg Canal and Lake Helen tailrace.

Recharge capacity for the Gothenburg Canal south of Golf Course site is summarized in **Table 19**. Yield for the Type I/II recharge project configuration would be achieved through natural return flows to the Platte River. The resulting yield and project efficiencies (i.e., yield as percent of total diversion) are shown in **Table 20**. Recharge capacity, resulting yield, and project efficiencies would be identical for the two scenarios considered, regardless of whether diversions are made using the Gothenburg Canal only, or if a combination of Gothenburg Canal and headgate well diversions are used. The two scenarios for types of diversions would only differ in cost, which is described after this discussion on recharge capacity and project yield. In addition to the yield shown in the table, approximately 2,790 AFY of return flows would not reduce shortages to target flows because of the timing of the return flows during periods of excesses to target flows. These additional return flows could potentially be captured by other Program water projects (e.g., reregulating storage) and used to reduce shortages to target flows at a later time, or used by Nebraska to offset post-1997 depletions as part of their PRRIP depletions plan. Average monthly diversions, yield at Grand Island, and return flows at Grand Island not credited to yield are provided in **Appendix C**.

Table 19. Physical Recharge Characteristics for the Gothenburg Canal South of Golf Course (Type I/II)

Number of Basins	1
Total Area	88 acres
Active Recharge Area[1]	35 acres
Constructed Basin Infiltration Rate	2 feet per day
Recharge Basin Rate of Recharge	70 AFD (35 cfs)
Canal Seepage (12% of diversion)	9.5 AFD (4.8 cfs)
Total Recharge Capacity[2]	**80 AFD (40 cfs)**

Notes:
[1] Active recharge area calculated as total area less 20 percent for infrastructure requirements and an additional 50 percent out of operation for maintenance/cleaning.

Table 20. Yield Estimates for Gothenburg Canal South of Golf Course

	Yield[1] and Efficiency[2] by Location (AFY)	
Diversions (AFY)	**Project Location**	**Grand Island**
9,297	4,254 (46%)	3,523 (38%)

Notes:
[1] Yield defined as the volume of return flows that can be credited to reducing target flow shortages.
[2] Efficiency calculated as yield divided by diversions.

Cost estimates for the Gothenburg Canal south of Golf Course Type I/II configuration were developed assuming that the yield will come from ground water return flows. Costs were developed separately for the two diversion scenarios. Capital and O&M costs are presented in **Table 21** and **Table 22**, respectively for the scenario with canal diversions only, and in **Table 23** and **Table 24** for the scenario with canal and headgate well diversions.

Table 21. Capital Cost Estimates for Gothenburg Canal South of Golf Course (Canal Diversions Only)

Description	Approximate Quantity	Unit	Unit Cost	Extended Cost
Mobilization/Demobilization	1	LS	$25,000	$25,000
Basin Excavation	225,867	YD	$1.50	$339,000
Diversion Structure	1	LS	$35,000	$35,000
SCADA	1	LS	$ 5,000.00	$5,000
Rip-rap, bank protection	500	YD	$ 50.00	$25,000
Rip-rap tailrace (1,320'x10'x1')	489	YD	$30	$15,000
Improve Tailrace	7,770	Ft	$3	$23,000
Improve Drain to Tailrace	12,200	Ft	$3	$37,000
Discharge Structure at Basin	1	LS	$10,000	$10,000
Land	88	AC	$ 4,000.00	$352,000
Sub-total				$856,000
Eng. & Permitting @ 10%				$86,000
Contingency @ 20%				$171,000
Total Capital Cost				**$1,113,000**

Table 22. Annual O&M Costs for Gothenburg Canal South of Golf Course (Canal Diversions Only)

Description	Approximate Quantity	Unit	Unit Cost	Extended Cost
Annual O&M	$761,000[1]	% capital	1.75%	$13,318
Total Annual O&M Cost				**$13,318**

Notes:
[1] Annual O&M based on total capital cost minus cost of land

Table 23. Capital Cost Estimates for Gothenburg Canal South of Golf Course (Canal and Headgate Well Diversions)

Description	Approximate Quantity	Unit	Unit Cost	Extended Cost
Mobilization/Demobilization	1	LS	$35,000	$42,000
Basin Excavation	225,867	YD	$1.50	$339,000
Diversion Structure	1	LS	$35,000	$35,000
SCADA	7	LS	$5,000	$35,000
Rip-rap, bank protection	500	YD	$30	$15,000
Rip-rap tailrace (1,320’x10’x1’)	489	YD	$30	$15,000
Improve Tailrace	7,770	Ft	$3	$23,000
Improve Drain to Tailrace	12,200	Ft	$3	$37,000
Discharge Structure at Basin	1	LS	$10,000	$10,000
Land	88	AC	$4,000	$352,000
Headgate wells	6	LS	$75,000	$450,000
Discharge structure at canal	1	LS	$10,000	$10,000
PVC Pipe: 16-inch	300	FT	$32.00	$10,000
PVC Pipe: 24-inch	500	FT	$ 48.00	$24,000
PVC Pipe: 30-inch	400	FT	$ 60.00	$24,000
PVC Pipe: 36-inch	400	FT	$ 72.00	$29,000
Power	1600	FT	$ 5.00	$8,000
Sub-total				$1,458,000
Eng. & Permitting @ 10%				$146,000
Contingency @ 20%				$292,000
Total Capital Cost				**$1,896,000**

Table 24. Annual O&M Costs for Gothenburg Canal South of Golf Course (Canal and Headgate Well Diversions)

Description	Approximate Quantity	Unit	Unit Cost	Extended Cost
Annual O&M (except for wells)	$1,094,000 [1]	% capital	1.75%	$19,145
Annual O&M Wells	3	LS	$1,000	$3,000
Power Costs				
Demand Charge	62	KW	$29.25	$1,818
Pumping Cost	1,809	Hr	$7	$12,755
Total Annual O&M Cost				**$36,718**

Notes:
[1] Annual O&M based on total capital cost minus capital cost of wells and land costs

Based on capital cost of $1.11 M and annual O&M costs of $13,000, and assuming a 50 year project life with a 3 percent discount rate, the total unit cost for the Gothenburg South of Golf Course Type I/II configuration with canal diversions only for the 1947 to 1994 scoring period would be approximately $16 per acre-foot per year based on project yield (i.e., reductions to target flow shortages) at Grand Island.

Based on capital cost of $1.9 M and annual O&M costs of $33,000, and assuming a 50 year project life with a 3 percent discount rate, the total unit cost for the Gothenburg South of Golf

Course Type I/II configuration with canal and headgate diversions would be approximately $31 per acre-foot per year based on project yield (i.e., reductions to target flow shortages) at Grand Island.

D. Type III Recharge (Example Project: B1 Reservoir)

The Type III recharge concept would include diversions of excess flows for recharge using the Gothenburg Canal. Excess flows would be conveyed to the existing B1 Reservoir owned by CPNRD. CPNRD currently uses B1 Reservoir to recharge the ground water aquifer using surface water delivered through Gothenburg Canal. The reservoir is typically used for recharge 1 out of every 3 years, under CPNRD's permit A-15890 with the Nebraska DNR to store water for the following purposes: supplemental storage, ground water recharge for agriculture and domestic supply, and fish and wildlife. CPNRD's water right permits diversion of approximately 4,000 AFY of natural flow that is typically available in spring and fall but not during the summer irrigation season. CPNRD also has a water right for storing Buffalo Creek stormflow.

Yield would occur through a combination of active ground water pumping using newly installed wells around B1 Reservoir, and in-lieu ground water pumping with an exchange for surface water in Lake McConaughy. B1 Reservoir is approximately 10 miles from the Platte River, and as a result ground water return flows to the river would be minimal within the first increment of the Program. Use of ground water wells to actively pump recharged water back to the Platte River would allow greater control over the timing of yield to the Platte River, and the efficiency of this type of project would be greater than that for the previous projects that rely on natural return flows to the Platte River. However, the additional cost of installing new wells for active pumping is an additional cost that would not be part of projects relying on natural return flows.

Institutional and regulatory requirements may provide limitations on the ability to use in-lieu ground water pumping with an exchange for surface water in Lake McConaughy. There is some uncertainty in the likelihood of approval for changing the use of existing surface water rights from irrigation to use for instream flows. This uncertainty should be addressed in any future studies for recharge at B1 Reservoir with in-lieu pumping to recover recharged water.

A general layout of the B1 Reservoir recharge site is provided in **Figure 12**. B1 Reservoir has an approximate total storage capacity of 8,800 AF at an elevation of 2,554 feet, with a surface area of approximately 550 acres. Active storage capacity available for recharge operations is approximately 2,015 AF (corresponding surface area of 221 acres), and the remaining storage capacity is reserved for flood control. Historical infiltration rates have ranged from 10 to 24 AF per day (CPNRD 2009).

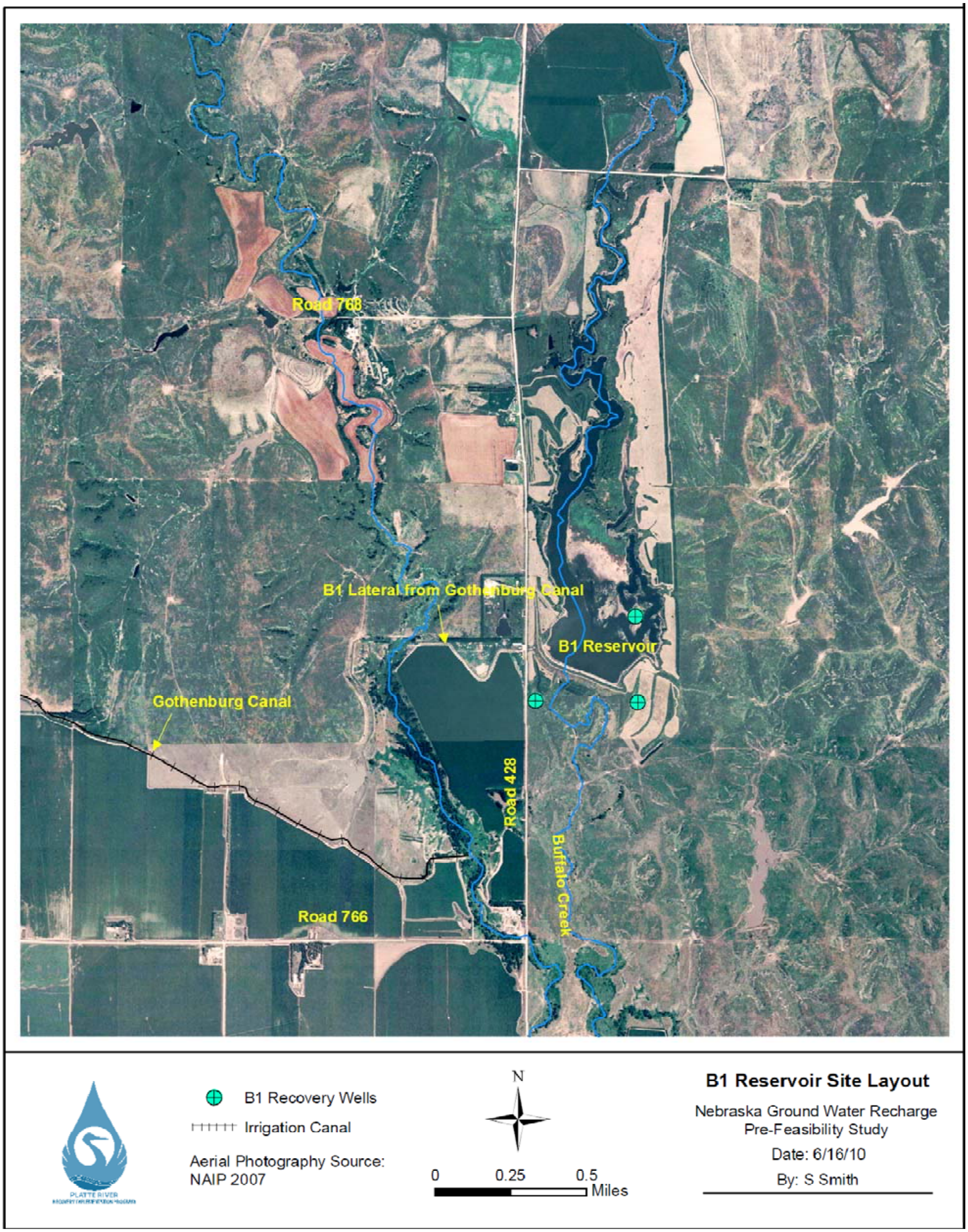


Figure 12. B1 Reservoir Site Layout

The following assumptions were used in determining recharge potential at the B1 Reservoir site:

- Diversion and recharge operations were assumed to occur throughout the year with the exception of December through February to avoid potential icing problems. Diversions and recharge would continue throughout the irrigation season, depending on available capacity in the Gothenburg Canal above irrigation deliveries in the canal. Diversions during irrigation season were considered for this project (and not for the previous two projects) because of limitations with winter diversions that are not an issue for the other projects. Diversions throughout the irrigation season would facilitate efficient use of available excess flows including any available excess irrigation deliveries that would have otherwise been wasted back to the Platte River. The rate of diversion is low enough (approximately 7.6 cfs) and it is therefore assumed that this additional water could be accommodated in the canal during the irrigation season without interference with irrigation deliveries.
- Seepage losses from the Gothenburg Canal between the canal headgate and B1 Reservoir were assumed to be 30 percent of the total diversion, based on CPNRD's permit to impound water at B1 Reservoir (DNR 1981). Canal seepage losses that would occur outside of the typical Gothenburg Canal operating season (April through September) were assumed to be recovered as project yield through in-lieu pumping. Canal seepage losses that would occur during the April to September period were assumed to have been present historically, and were not assumed to be credited towards project yield as a result.
- Recharge would primarily occur through the floor of the existing B1 Reservoir, with water impounded behind the existing B1 embankment. Moderate preparation (e.g., scarification and removal of fine sediments) is anticipated for B1 Reservoir. Based on historical infiltration rates, a recharge rate of 15 AF per day was assumed for this study (0.07 feet per day assuming a surface area of 220 acres for recharge). The relatively low infiltration rate is consistent with observations of soil conditions (silt loam with clay) at the B1 Reservoir site during field reconnaissance in March 2010.
- Evaporation losses for B1 Reservoir recharge operations were estimated to be 134 AF over 9 months of recharge operations. Evaporation losses were calculated assuming a recharge surface area of 220 acres, a net effective evaporation rate of 0.61 ft over 9 months of recharge operations. The rate of evaporation was based on average pan evaporation of 45 inches per year, pan evaporation coefficient of 0.75, and average annual precipitation of 24 inches per year from the Eastern Model Unit documentation (COHST 2007). Because evaporative losses represent approximately 5 percent of total diversions, total diversions for recharge at B1 Reservoir included evaporative losses.
- Three (3) new ground water wells would be installed to actively recover recharged water and discharge to Buffalo Creek for delivery to the Platte River during times of shortages to target flows. Each well would have a pumping capacity of 700 gpm, which is lower than wells located in the alluvial valley that would have capacity closer to 1,000 gpm. The lower capacity for wells near B1 Reservoir reflects the relatively close spacing of wells, the greater distance from the river (a significant boundary), and the assumption that aquifer properties may not be as favorable here as they would be adjacent to the river. The wells would include those used to actively recover recharged water at the reservoir, and also new irrigation wells elsewhere along the Gothenburg Canal to capture recharged water for in-lieu pumping. This is a conservative estimate for the number of

new wells that would be required, because in-lieu pumping may be achieved using existing supplemental irrigation wells under contract between the Program and existing well owners. Total pumping capacity would be approximately 1,400 gpm (6.3 AFD) at any given time, assuming 20 percent of the wells would be off for maintenance.

- A total of approximately 190 AF per month would be pumped from the recovery wells from March to August (i.e., when shortages to target flows are greatest) to fully recover the volume of water recharged at the B1 Reservoir site. Monthly pumping rates for active pumping were calculated as the annual average volume of water recharged at B1 Reservoir (70 percent of total diversions to Gothenburg Canal) less evaporation. Monthly pumping rates were assumed to be constant March through August for this pre-feasibility analysis, but could be refined in further analyses if the B1 site configuration is recommended for additional study. For example, monthly pumping rates could vary based on shortages to target flows in order to maximize yield and project efficiency.
- Transit losses for recovered water that is pumped to Buffalo Creek for return to the Platte River were estimated by first determining the portion of Buffalo Creek that generally loses water to the underlying ground water system (i.e., the portion where transit losses would occur). The area of Buffalo Creek assumed to lose water to the ground water system was estimated to be the portion between B1 Reservoir and the Dawson County Canal (approximately 5.5 miles). This assumption was based on field observations during March 2010 field reconnaissance for this study, and other long-term observations (CPNRD 2010). The unit transit loss for Buffalo Creek was estimated to be 0.61 cfs per mile, assuming a wetted perimeter of 10 feet and an infiltration rate of 1 foot per day. This estimate for seepage loss from Buffalo Creek is similar to the estimate for Gothenburg Canal Lateral 30, in the same area as Buffalo Creek, as estimated by CPNRD and NPPD (2005). Total losses between B1 Reservoir and the Platte River would be approximately 3.4 cfs for the 5.5 mile losing reach of Buffalo Creek (approximately 200 AF per month). Water lost in transit was assumed to be available for in-lieu pumping, and as a result was not discounted from the yield of the project.
- Because transit losses in Buffalo Creek would be approximately 200 AF per month, and active pumping would only yield approximately 190 AF per month at B1 Reservoir, there would be no yield from active pumping at the Platte River. However, active pumping would effectively distribute water to a greater area along Buffalo Creek, where in-lieu pumping could be used to recover all water lost in transit from the creek.
- Approximately 470 AF per month of yield from June through August from in-lieu pumping would be realized at Lake McConaughy, assuming in-lieu pumping would occur at a constant rate over the typical June to August irrigation season. The monthly in-lieu pumping yield was calculated as the amount of water lost in transit along Gothenburg Canal and recovered through in-lieu pumping (30 percent of total diversions to Gothenburg Canal), plus transit losses along Buffalo Creek associated with active pumping, pro-rated to the 3 months of in-lieu pumping during the irrigation season.
- Accounting of Program water in Lake McConaughy from in-lieu pumping would include the volume of water pumped at the irrigator's field, plus transit losses that would have occurred for a surface water release from Lake McConaughy (approximately 5 percent transit loss from Lake McConaughy to Gothenburg Canal headgate on average according to the WMC Loss Model).

Recharge capacity for the B1 Reservoir site is summarized in **Table 25**. The resulting yield and project efficiencies (i.e., yield as percent of total diversion) are shown in **Table 26**. In addition to the yield shown in the table, approximately 360 AFY of return flows would not reduce shortages to target flows because of the timing of the return flows during periods of excesses to target flows. These additional return flows could potentially be captured by headgate wells and returned to recharge basins, or captured other Program water projects (e.g., reregulating storage) and used to reduce shortages to target flows at a later time, or used by Nebraska to offset post-1997 depletions as part of their PRRIP depletions plan. Average monthly diversions, yield at Grand Island, and return flows at Grand Island not credited to yield are provided in **Appendix C**.

Table 25. B1 Reservoir Type III Physical Recharge Characteristics

Total Area	220 acres
Active Recharge Area[1]	220 acres
Infiltration Rate	0.07 foot per day
Recharge Capacity	**15 AFD (7.6 cfs)**

Notes:
[1] Active recharge area is equal to total area for the B1 Reservoir site, because access roads are already in place at the existing reservoir site, and maintenance would occur during the winter months when recharge would not take place because of icing concerns for Gothenburg Canal.

Table 26. Yield Estimates for B1 Reservoir Type III Site

	Yield[1] and Efficiency[2] at Project Location (AFY)			**Yield[1] and Efficiency[2] at Grand Island (AFY)**		
Diversions[3] (AFY)	Active Pumping to Buffalo Creek[4]	In-Lieu Pumping[5]	Total	Active Pumping to Buffalo Creek[4]	In-Lieu Pumping	Total
1,676	0	1,021	1,021 (61%)	0	712	712 (42%)

Notes:
[1] Yield defined as the volume of return flows that can be credited to reducing target flow shortages.
[2] Efficiency calculated as yield divided by diversions.
[3] Diversions include those needed for recharge and canal losses, plus diversions to meet estimated evaporative losses of 134 AF per year over the 9 month period of operation.
[4] Yield from active pumping equals total recharge at B1 Reservoir, minus transit losses in Buffalo Creek (3.4 cfs). Yield from active pumping is at Associated Habitat at the confluence of Buffalo Creek and the Platte River.
[5] Yield from in-lieu pumping equals Gothenburg Canal seepage (30 percent of diversions) plus Buffalo Creek transit losses associated with conveyance of actively pumped water to the Platte River. Yield of in-lieu pumping is at Lake McConaughy.

Cost estimates for the Gothenburg Canal to B1 Reservoir Type III configuration were developed assuming that the yield will come from a combination of actively pumped return flows to Buffalo Creek and in-lieu pumping along Gothenburg Canal and Buffalo Creek. Capital and O&M cost estimates for the Gothenburg Canal to B1 Reservoir Type III configuration are provided in **Table 27** and **Table 28**, respectively.

Table 27. Gothenburg Canal to B1 Reservoir Capital Cost Estimates

Description	Approximate Quantity	Unit	Unit Cost	Extended Cost
Mobilization/Demobilization	1	LS	$27,000	$27,000
Canal Improvement	15,840	Ft	$3	$48,000
Reservoir Preparation	550	AC	$100.00	$55,000
Discharge Structure in Stream	1	LS	$2,000	$2,000
SCADA	8	LS	$5,000	$40,000
Recovery wells	3	LS	$75,000	$225,000
Power	5280	Ft	$5	$26,000
Sub-Total				$408,000
Engineering & Permitting (10%)				$41,000
Contingency (20%)				$82,000
Total Capital Cost				**$531,000**

Table 28. Annual O&M Cost Estimates for Gothenburg Canal to B1 Reservoir Configuration

Description	Approximate Quantity	Unit	Unit Cost	Extended Cost
Annual O&M (except for wells)	$306,000[1]	% of Capital	1.75%	$5,355
Annual O&M Wells	3	per well	$1,000	$3,000
Power Costs				
Demand Charge	16	KW	$29.25	$477
Pumping Cost	5,600	Hrs	$1.85	$10,360
Total Annual O&M Cost				**$19,190**

Notes:
[1] Annual O&M based on total capital cost ($0.53 M) minus capital cost of wells ($225,000). O&M costs include demand charge and pumping cost for in-lieu pumping.

Based on capital cost of $531,000 and annual O&M costs of $19,190, and assuming a 50 year project life with a 3 percent discount rate, the total unit cost for the Gothenburg Canal to B1 Reservoir Type III recharge project would be approximately $56 per acre-foot per year based on project yield (i.e., reductions to target flow shortages) at Grand Island.

E. Type IV Recharge (Example Project: High Ground Water Southwest of Overton)

The Type IV recharge concept would include pumping areas of high ground water along Spring Creek approximately 2.5 miles southwest of Overton. Depth to ground water is approximately 7 feet below ground surface in this area, and pumping of high ground water for the Program's use may be advantageous for both the Program and local irrigators and home owners. Pumping of high ground water could reduce problems associated with high ground water including water logged crops and basements.

A like amount of water may need to be recharged in order to offset the volume of water pumped from the ground water aquifer and maintain the overall water balance for the aquifer. Recharge could be achieved through canal seepage from Dawson County Canal and/or Gothenburg Canal as needed. The ability to recharge a like amount of water in Dawson County and/or Gothenburg

Canal should be verified in future feasibility studies. In any case, pumped ground water would be discharged to Spring Creek for conveyance to the Platte River. Ground water would be pumped using new high capacity irrigation wells within 500 feet of Spring Creek, through an agreement with the well owners where the Program would pay pumping and associated maintenance costs for use of the wells.

There is some uncertainty regarding the institutional and regulatory requirements for permitting this type of project. Specifically, it is unclear whether wells in high ground water areas could be pumped without recharging the same amount of water at the same location to effectively have no impact on the aquifer. Ground water recharge elsewhere in the aquifer may be required to offset the volume of water pumped from the aquifer southwest of Overton. Input should be solicited from potentially affected parties regarding potential effects of the proposed pumping and possible mitigation for the effects. Potentially affected parties to be consulted include the Nebraska DNR, Nebraska Natural Resource Districts, NPPD, and potentially affected irrigators in the vicinity of the high ground water area to be pumped. Uncertainties regarding institutional and regulatory requirements should be addressed in any future analyses of this type of project.

A general layout of the High Ground Water Southwest of Overton site is provided in **Figure 13**.

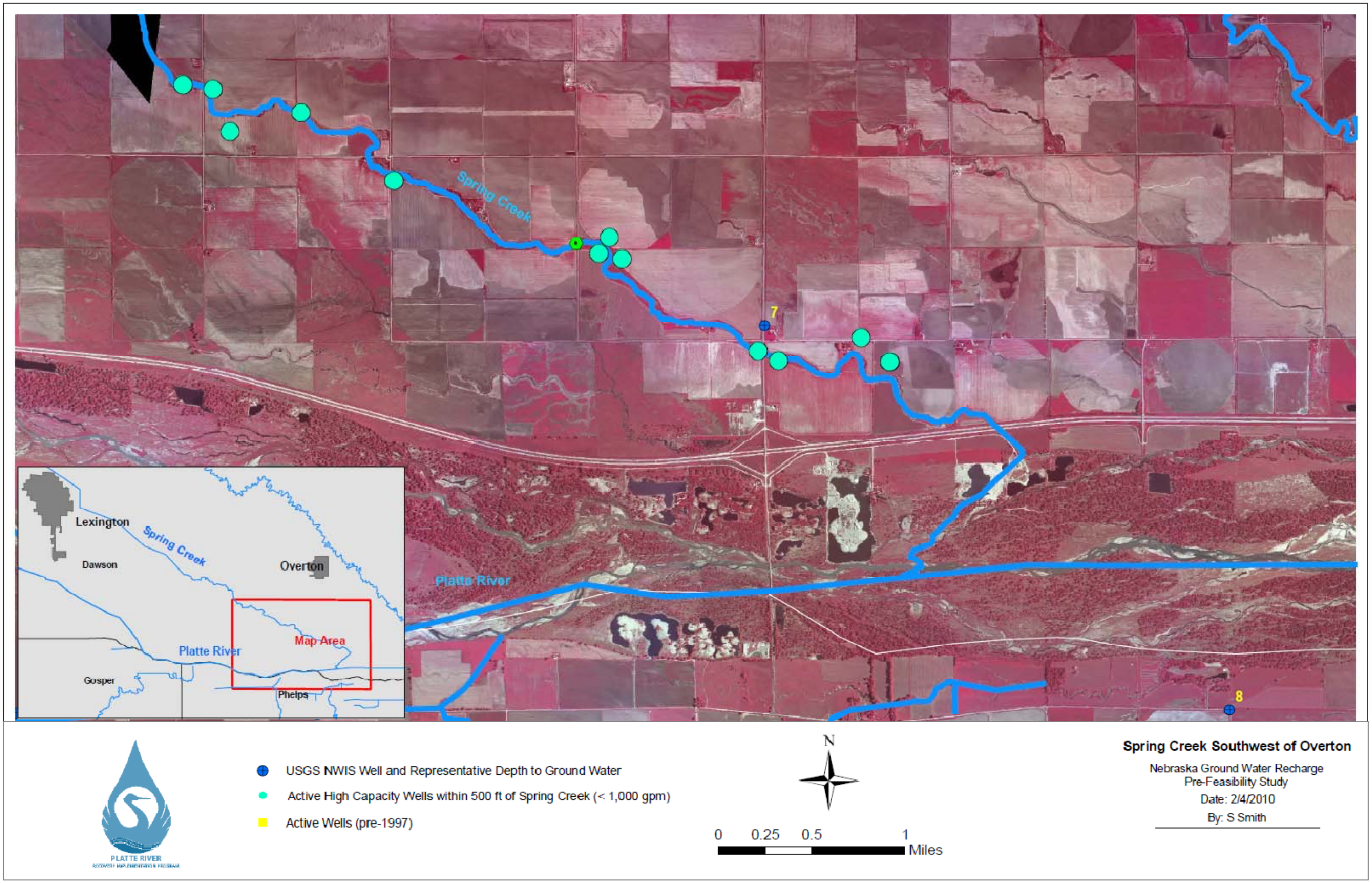


Figure 13. High Ground Water Southwest of Overton Site Layout

The following assumptions were used in determining yield and recharge potential at the High ground water southwest of Overton site:

- If needed, diversion of excess flows to Gothenburg and/or Dawson County canals for dispersed recharge would be limited to March through November (i.e., months without freezing issues). The objective would be to recharge the same amount of water that was pumped in a given year, resulting in no net change to overall aquifer storage.
- There would be no need for constructing recharge basins, because recharge would be limited to dispersed recharge from canal seepage.
- Twelve (12) new high capacity irrigation wells were assumed to be used for pumping areas of high ground water to Spring Creek. Each well would have a pumping capacity of 1,000 gallons per minute (gpm), and the wells would be operated continuously from March through August (i.e., when shortages to target flows are the greatest). Total pumping capacity would be 9,600 gpm (42 AFD) at any given time, assuming 20 percent of the wells would be off for maintenance. Pumping rates would vary day to day according to shortages to target flows, but would be a maximum of 9,600 gpm.
- Yield would occur as a result of ground water actively pumped to Spring Creek for conveyance to the Platte River. Pumping rates would vary on a daily basis according to shortages to target flows in order to maximize the efficiency of the project. There would be no transit losses for conveyance in Spring Creek to the Platte River, because Spring Creek is assumed to be a gaining stream in this reach as a result of high ground water levels.
- There would be no evaporative losses for the High Ground Water Southwest of Overton configuration, because constructed recharge basins would not be used.
- Yield at Grand Island was discounted to reflect the portion of the Overton to Grand Island reach that return flows would affect (i.e., yield was multiplied by 97 percent to determine the portion of yield that could be credited to the project's score).

The resulting yield and project efficiencies (i.e., yield as percent of total diversion) are shown in **Table 29**. In addition to the yield shown in the table, approximately 150 AFY of return flows would not be credited to yield for this project configuration because of the discounted yield to reflect the portion of the Overton to Grand Island reach affected by return flows. Average monthly yield at Grand Island and return flows at Grand Island not credited to yield are provided in **Appendix C**.

Table 29. Yield Estimates for High Ground Water Southwest of Overton Type IV Site

	Yield[1] and Efficiency[2] by Location (AFY)	
Diversions (AFY)	**Project Location**	**Grand Island**
5,141	4,962 (97%)	4,229 (82%)

Notes:
[1] Yield defined as the volume of return flows that can be credited to reducing target flow shortages, and reduced to reflect the portion of the Overton to Grand Island reach that would be affected by the return flows.
[2] Efficiency calculated as yield divided by diversions.

Cost estimates for the High Ground Water Southwest of Overton Type IV configuration were developed assuming that the yield would result from active pumping to Spring Creek. Capital and annual O&M cost estimates for the High Ground Water Southwest of Overton Type IV configuration are provided in **Table 30** and **Table 31**, respectively.

Table 30. High Ground Water Southwest of Overton Capital Cost Estimates

Description	Approximate Quantity	Unit	Unit Cost	Extended Cost
Mobilization/Demobilization	1	LS	$33,000	$33,000
Well Construction	12	LS	$75,000	$900,000
SCADA	12	LS	$5,000	$60,000
PVC Pipe: 12-inch (100'/well)	1200	FT	$24	$29,000
Discharge structure at stream	12	LS	$5,000	$24,000
Rip-rap, stream bed protection	12	LS	$2,000	$24,000
Land for well and pipeline	12	AC	$4,000	$48,000
Sub-Total				$1,118,000
Engineering & Permitting (10%)				$112,000
Contingency (20%)				$224,000
Total Capital Cost				**$1,454,000**

Table 31. Annual O&M Costs for High Ground Water Southwest of Overton Type IV Configuration

Description	Approximate Quantity	Unit	Unit Cost	Extended Cost
Annual O&M for Wells	12	LS	$1,000	$12,000
Power Costs				
Demand Charge	75	KW	$48	$3,616
Pumping Cost	4,800	Hr	$9	$37,413
Total Annual O&M Cost				**$53,029**

Based on capital cost of $1.45 M and annual O&M costs of $53,000, and assuming a 50 year project life with a 3 percent discount rate, the total unit cost for the High ground water southwest of Overton Type IV recharge project would be approximately $26 per acre-foot per year based on project yield (i.e., reductions to target flow shortages) at Grand Island.

VIII. SUMMARY AND RECOMMENDATIONS FOR ADDITIONAL STUDY

A. Summary of Preliminary Feasibility Study Findings

The analyses completed for this preliminary feasibility study helped to identify the driving influences on yield and cost of feasible project concepts and configurations for the Nebraska Ground Water Recharge project. The following is a summary of major findings from this study:

1. Locations of potential ground water recharge should include sites along the Gothenburg and Dawson County Canal as originally conceived in the 2000 WAP, but also should include sites along the Phelps County Canal and other sites not located along existing irrigation canals that could be fed by alluvial "headgate wells."
2. Relative to ground water recharge projects in Colorado (e.g., Tamarack), yield of ground water recharge projects in Nebraska may be limited by a shallow and flat ground water table.
3. Elements of ground water management can be combined with ground water recharge projects in order to increase project yield.
4. Diversion of excess Platte River flows for recharge projects could be achieved using existing irrigation canals, and could also occur through the use of alluvial "headgate wells."
5. Recharge could be achieved over a broad area via intentional ground water recharge from canal seepage, and/or at discrete locations using constructed recharge basins.
6. Through the use of ground water management techniques and recharge at constructed recharge basins, the yield of ground water recharge projects would be higher than the yield described for the original Nebraska Ground Water Recharge projects in the 2000 WAP.
7. Yield of any ground water recharge project will be highly dependent on potential recharge rates at project locations. Soils in the study area are primarily silt loam, which would have low to moderate recharge rates. However, there were isolated areas of more sandy material that would have moderate to high recharge rates.
8. Project efficiency, calculated as the percentage of diverted water that can be applied towards the reduction of shortages to target flows, is relatively low (e.g., approximately 40 percent) for sites that rely on ground water return flows to the Platte River. Project efficiency can be increased by combining recharge with ground water management techniques, and also if projects were assumed to be operated on a daily basis (as opposed to monthly operations assumed for this pre-feasibility study). This would be particularly true for projects including active pumping of recharged water back to the Platte River during times of shortages to target flows.
9. Low project efficiency may not necessarily be a "bad thing." Excess flows retimed to the Platte River but not credited towards ground water recharge project yield could potentially be utilized by other WAP projects (e.g., re-regulating reservoirs).
10. The ground water table in the study area is relatively shallow, with typical depth to water of 5 to 10 feet near the Platte River and generally less than 30 feet for sites further from the Platte River. The potential for ground water recharge would vary from site to site depending on the depth to water.

11. Winter operations in irrigation canals may be limited by icing problems, especially for portions of the canals with smaller cross-sectional area. Issues with winter icing can be minimized by maintaining a continuous flow through the canals using a drain or wasteway to return unused flows back to the Platte River or through the use of "headgate wells" that would divert warmer water with less potential for icing.
12. Recharge sites close enough to the Platte River and/or drain or tributary to the Platte River, which result in substantial ground water return flows within the First Increment of the Program, would provide yield at a lower unit cost than sites further from the Platte River that would rely on pumping recharged water back to the river.

B. Recommendations for Additional Study

The reconnaissance-level analyses completed for this pre-feasibility study could be improved with additional studies to refine project descriptions and yield/cost results. Principal objectives of a feasibility study include the following factors:

- Initiate process to address permitting and institutional requirements for demonstration projects and full-scale projects
- Refine recharge project assumptions from pre-feasibility analysis based on field investigations
- Determine physical feasibility and potential effects of ground water recharge through a demonstration project (determine long-term sustainable infiltration rate, and effects of ground water recharge on local ground water conditions including downstream ground water drains)
- Refine pre-feasibility cost estimates for full-scale recharge project(s)
- Final recommendation for full-scale recharge project(s)

Project configurations recommended for additional analyses in a feasibility study are the Gothenburg Canal South of Golf Course Site, and the Phelps 9.7 Site. These sites are recommended for feasibility-level analyses because of the generally high yield and low unit cost for these configurations.

Assuming the permitting and institutional issues associated with recharge demonstration project(s) can be resolved, a feasibility level study is recommended for initiation in the fall of 2010. It is anticipated that the feasibility study would be completed by the fall of 2011. Ultimately the feasibility study approach will be based on methods agreed to by the Program participants and the consultant selected to complete the feasibility study. However, the feasibility study is anticipated to include the following steps:

1. Permitting coordination – acquire up to 270 AF of water supply for pilot-scale demonstration projects, and initiate permitting coordination for full-scale recharge project
2. Landowner coordination – reach agreements with current landowners for completion of fieldwork and pilot-scale demonstration projects on their property, including potential lease and/or crop yield guarantee payments

3. Fieldwork and analysis – complete field investigation to collect information needed to design demonstration projects; activities likely to include installation of monitoring wells, site-specific investigations, aquifer pump test(s), and ground water mounding analyses
4. Pilot-scale demonstration recharge projects – design, build, and operate pilot-scale recharge projects to determine actual recharge rates, effects on local ground water and nearby drains/streams
5. Yield and cost estimate refinement – estimate yield and cost of feasibility study sites (Gothenburg Canal South of Golf Course and the Phelps 9.7) based on data collected in feasibility study
6. Reporting and final recommendation – complete final report documenting results of feasibility study, and recommending final project(s) for full-scale ground water recharge

Step 1 – Permitting Coordination

As described above in **Section VI**, water will need to be acquired for any pilot-scale demonstration project. The ED Office will work with potential project sponsors (NPPD, CNPPID, and CPNRD) to obtain a small amount of short-term water supply (e.g., 3 months worth of water) for a potential demonstration project. An agreement will be reached between the Program and project sponsor(s) in the form of a Memorandum of Agreement (MOA) prior to beginning design of facilities for a demonstration project. Coordination with DNR, NRDs, and potential project sponsors will also occur to determine the permitting process for implementing full-scale recharge projects, and that process will be initiated due to its anticipated length of duration.

Step 2 – Landowner Coordination

Concurrent with development of an MOA with project sponsors, the ED Office will also work with the irrigation district to coordinate land access for potential pilot-scale projects from landowners. Temporary leasing of land will be desirable, which would allow flexibility for permanently acquiring the land if the results of the pilot-scale demonstration projects indicate promising potential for a full-scale project.

Step 3 – Fieldwork and Analysis

Installation of approximately 8 monitoring wells should be installed at the two feasibility study sites (i.e., 4 wells at each of the 2 sites) prior to designing a demonstration project (Step 4 below) to verify depth to water and the related feasibility of ground water recharge. Aquifer pumping tests could also be conducted using existing agricultural irrigation supply wells in order to refine assumptions on aquifer properties used to estimate yield of recharge projects in the pre-feasibility analysis.

Analytical analyses to predict the effects of pilot-scale recharge projects should be completed for both of the feasibility study sites prior to design of pilot-scale recharge facilities. The analytical analyses should be based on commonly accepted analytical solutions for ground water conditions such as the Theis Equation or solutions developed specifically for predicting ground water mounds such as the method developed by Hantush (1967). The analytical analyses of effects on ground water conditions should be used to estimate the response of the ground water aquifer to pilot-scale recharge prior to implementation of pilot-scale recharge projects. Effects on depth to water, areal extent of ground water mounding, and discharge to nearby ground water drains should be predicted. Results of pilot-scale recharge, based on monitoring during the pilot-scale recharge projects, should then be used to adjust the assumed values for aquifer properties such as hydraulic conductivity and storage coefficient. Results of the analytical analyses would be used to refine yield and cost estimates for the feasibility study sites (Step 5 below). Additionally, refined aquifer properties could be used in numerical ground water models that could be constructed after completion of the feasibility study and prior to design and construction of the full-scale recharge project(s).

Additional refinement of pre-feasibility recharge project configurations may be done, including inclusion of additional ground water management scenarios. Integration of ground water recharge components with other projects (e.g., Elm Creek Reservoir and CNPPID reregulating reservoir) may also be possible. Integration with some form of reregulating storage could increase the efficiency of ground water recharge projects by diverting ground water recharge project return flows to reregulating storage when those return flows would return to the Platte River during times of excesses when they could not be applied to reducing shortages to target flows.

Step 4 – Pilot-Scale Recharge Demonstration Projects

Pilot-scale demonstration projects are recommended following completion of permitting, land owner coordination, field investigations, and analytical analyses. The objectives of a demonstration project are:

- Determine long-term sustainable infiltration rates
- Determine effects of ground water recharge on local ground water conditions including the potential effects on wells and irrigated land associated with recharge
- Determine effects of ground water recharge on downstream ground water drains

The demonstration project could include a single recharge pond at each of the two feasibility-level sites, approximately 1 acre in surface area, formed behind a constructed embankment and utilizing natural topography where possible. The embankment could be constructed using excavated material from the site, and some clay may need to be imported from offsite to minimize seepage through the embankment. Pilot-scale recharge facilities would be designed in a manner conducive to expansion to full-scale recharge facilities if desirable.

A recharge rate of 2 feet per day is anticipated for the Gothenburg Canal south of Golf Course site, resulting in approximately 2 acre-feet per day (1 cfs) of continuous recharge. Recharge of 1.0 feet per day is anticipated for the Phelps 9.7 site, resulting in approximately 1.0 acre-feet per day (0.5 cfs). Recharge operations would be continuous for approximately 3 months. Pilot-scale recharge operations for the Gothenburg Canal south of Golf Course site would likely occur from March through May to avoid interference with the June to August irrigation period. Operations at the Phelps 9.7 site would likely occur from June through August to take advantage of water availability in Phelps County Canal. A yield guarantee would be paid to the owner of the Phelps

9.7 land to offset the lost revenue associated with interference from the pilot-scale recharge project. Total water needed for the pilot-scale feasibility study would be approximately 180 acre-feet for the Gothenburg Canal south of Golf Course site, and approximately 90 acre-feet for the Phelps 9.7 site.

Use of monitoring wells to track effects of demonstration project(s) on local ground water conditions is recommended (e.g., change in depth to water, and horizontal movement of recharged water away from the area near the recharge basin). Pressure transducers and data loggers should be installed in the monitoring wells to facilitate collection of water level data.

The influence of recharge activities on drains down gradient of the sites could be assessed with the installation of a monitoring weir on the drains (e.g., Parshall Flume). If the weir is installed, pressure transducers and data loggers should be installed for collection of continuous flow data.

Step 5 – Yield and Cost Estimates Refinement

Yield and cost estimates for the Gothenburg Canal south of Golf Course and Phelps 9.7 sites will be refined based on data collected during the feasibility study. Refined yield and cost estimates will build on those completed for this pre-feasibility study. The consultant selected to complete the feasibility study will work with the ED Office on yield/cost estimates, but the consultant will ultimately be responsible for determining the appropriate methods and assumptions for refinement of yield and cost estimates.

Step 6 – Reporting and Final Recommendation

Reporting and final project recommendation should incorporate findings from the demonstration projects, and should also include updated full-scale project yield and cost estimates for the two project configurations studied in the feasibility study. Updated full-scale project yield and cost estimates will build on estimates done for the pre-feasibility report. Final methods and results will be based on work to be completed by the consultant.

Anticipated next steps beyond the feasibility-level analyses described above include numerical ground water modeling and final project design based on the final project recommendation made at the conclusion of the feasibility study. An independent technical review of the final project design is also expected.

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Appendix A
Field Reconnaissance Summary
March 2010

TO: TECHNICAL WORK GROUP

FROM: STEVE SMITH

SUBJECT: NEBRASKA GROUND WATER RECHARGE FIELD RECON

DATE: MARCH 16, 2010, UPDATED APRIL 13, 2010

CC: JERRY KENNY AND BEORN COURTNEY

Field reconnaissance for potential recharge sites for the ground water recharge pre-feasibility study was conducted March 15, 2010. The following attendees participated: Duane Woodward (CPNRD), Cory Steinke (CNPPID), Randy Zachs (NPPD), Rob Ostergard (NPPD), Bill Hahn (Hahn Water Resources), and Steve Smith (ED Office). Activities were documented with notes, photographs, and video. The itinerary was as follows:

1. Sites west of Gothenburg along the Gothenburg Canal for recharge basins that would use the Lake Helen tailrace to cycle water back to the Platte River; including soil sampling
2. B1 Reservoir for soil sample to determine recharge potential
3. Berquist Lateral for potential recharge sites
4. High ground water southwest of Overton for ground water level measurements for potential to pump high ground water
5. Phelps 9.7 for soil sample to determine recharge potential, and also for topographic review for evaluation of feasibility of gravity feeding from the Phelps Co. Canal
6. Cottonwood Ranch and Cook/Dyer properties to determine if recharge sites exist far enough from the river for desired return flow timing

Main findings of the field reconnaissance were:

1. Feasibility of recharge site south of Gothenburg Canal and west of Gothenburg just east of where the canal crosses Hwy 30 would be limited, because there is not enough change in elevation from the canal to the site for gravity feeding the site.
2. Another site along Gothenburg Canal and south of the Wild Horse Golf Course (just west of Gothenburg) (N 40 deg 57.079', W 100 deg 11.717'; Elev 5365 ft) would be a better Type I site because:
    a. Topography would allow gravity feeding of site.
    b. There is plenty of fallow ground with undulations in topography that would limit costs of ring-dyke style embankment.
    c. Soil sample was collected to a depth of about 3.5 feet, and indicated fine sand indicative of high recharge potential (likely at least 2 to 3 ft per day). Soil classification summary is provided in the table below.
3. Lake Helen tailrace has a capacity of 150-200 cfs, and would enable Program to cycle water throughout the winter for recharge at sites near Wild Horse Golf Course described above.
4. Gothenburg Canal operating season should be September 1 through third week of June to avoid irrigation season.
5. Soils at B1 Reservoir were collected with hand auger at depth of up to 4.5 feet. Soils were silt loam, consistent with soil survey, and would result in poor recharge rates (<1 ft/day). Soil classification summary is provided in the table below.
6. Sites along Berquist Lateral close enough for delivery of water from "headgate" wells are too close to the Platte River to result in timing of return flows that Program is designing for.
7. Spring Creek had flow north of Cozad Canal at Road 766, indicating that it is relatively perennial (may be affected by the past few years being wetter than normal).

8. Depth to ground water along Spring Creek southwest of Overton is about 4 feet below ground, which would result in a feasible scenario of pumping high ground water to Spring Creek for return flows to the Platte River.
9. Soils at Phelps 9.7 site were collected with hand auger at depth of up to 4.5 feet. Soils were silt loam, consistent with soil survey, and would result in poor recharge rates (<1 ft/day). Soil classification summary is provided in the table below.
10. Constructed recharge basins north of Phelps Co Canal could likely be gravity fed from the canal.
11. Sites at Cook, Dyer, and Cottonwood Ranch are all too close to the Platte River to result in timing of return flows that Program is designing for. Additionally, ground water may be too shallow at these sites to result in enough aquifer freeboard for ground water recharge.

The most feasible recharge sites were determined to be the Gothenburg Canal near Wild Horse Golf Course (Type I – natural return flows at sites close to the Platte River) and High ground water southwest of Overton (Type IV pumping of high ground water levels). However, we will still run yield and cost analyses for all of the 4 recharge sites identified by the Technical Work Group (the additional 2 sites are B1 Reservoir and Phelps 9.7).

Soil Classification Summary for Samples Collected During Field Reconnaissance

Site and sample setting	Depth of Sample	Sample Description	USCS Classification[1)]
B1 Reservoir, floor of reservoir	8 inches	Damp to wet, medium gray, organic clayey silt, trace sand, moderately plastic, w/ roots and organic debris.	OL/OH
B1 Reservoir, floor of reservoir	3.5 feet	Damp to wet, medium to light gray, clayey silt, trace sand, moderately plastic w/ trace roots.	CL/CH
B1 Reservoir, first terrace (native soils)	2.5 feet	Damp to wet, medium to light gray, clayey silt, trace sand, moderately plastic w/ trace roots.	CL/CH
Field in Phelps Canal area, upper terrace along canal	3.0 feet	Dry, medium brown silt, w/ trace sand, trace clay, no plasticity, some roots.	ML
Field in Phelps Canal area, upper terrace along canal	4.5 feet	Dry, light brown silt, trace sand, no plasticity, trace roots.	ML
Field below Gothenburg Canal below golf course	3.0 feet	Dry, light brown very fine sand and silt, poorly graded, no plasticity.	SM

1) Liquid limits were not determined on soil samples, therefore some samples could not be classified relative to the liquid limit criteria. Accordingly, both soil classes are listed (above/below LL of 50).

Appendix B
Field Reconnaissance II Summary
May 2010

TO: TECHNICAL WORK GROUP

FROM: STEVE SMITH

SUBJECT: NEBRASKA GROUND WATER RECHARGE FIELD RECON II

DATE: JUNE 2, 2010, REVISED JUNE 9, 2010

CC: JERRY KENNY AND BEORN COURTNEY

Initial field reconnaissance for potential recharge sites for the ground water recharge pre-feasibility study was conducted March 15, 2010. A summary of those activities and results was distributed to the technical work group in a memo from the ED Office dated March 16, 2010 and updated April 13, 2010. Pre-feasibility analyses were subsequently completed for five potential recharge sites that were selected based on mapping of site properties and results of the March 15, 2010 field reconnaissance.

Additional field reconnaissance was determined to be useful in refining initial assumptions for site-specific recharge rates that were made for the pre-feasibility analyses. As a result, the ED Office completed percolation tests on May 24 and 25, 2010 for the following potential recharge sites:

1. Gothenburg Canal south of Wild Horse Golf Course
2. Phelps 9.7

This memorandum summarizes the methods used to complete the percolation tests, and documents the results of the tests.

The percolation tests were completed using the following methods:

1. Note: did not pre-soak percolation test hole, but it did rain the night before the percolation tests and, at each location, the soil was noticeably damp as it was removed from the test hole
2. Dug test hole approximately 18" deep using a clam shell style post-hole digger
3. Set 24" long, 4" diameter PVC casing (percometer) in the test hole to minimize the effect of horizontal flow on resulting recharge rates
4. Poured water inside the 4" PVC to the top of casing (TOC)
5. Estimated vertical infiltration rate by measuring depth to water in PVC percometer
6. Recorded depth to water on a 5 to 10 minute recurrence interval until rate of infiltration was constant (i.e., steady-state) for at least 30 minutes

A picture of the percolation test setup is provided in the figure below. The figure shown is for the Phelps 9.7 location, and the setup was the same for the Gothenburg Canal at Golf Course site.

Phelps 9.7 Single-Ring Infiltrometer Percolation Test with 4" PVC (Phelps 9.7)

Results of the percolation tests for each of the sites were as follows.

Gothenburg Canal south of Golf Course

Date of test: May 24, 2010
Location of test hole: N 40 deg 57' 10.6", W 100 deg 12'18.5", Elev 2,583
Depth of hole: 19" below ground surface (bgs)
Soil classification: Damp, brown, fine to medium, poorly graded SAND (SP)
Installed 4" diameter PVC percometer in hole, filled with water, and recorded depth to water (DTW) below top of casing (TOC)

Table 1. Gothenburg Canal south of Golf Course Site – Percolation Test Results

Time	DTW (inches below TOC)	Percolation Rate (inches per 10 min)
18:50	4 0/16	--
18:55	5 1/16	34/16
19:00	6 1/16	32/16
19:10	7 10/16	25/16
19:20	8 13/16	19/16
19:30	10 2/16	21/16
19:40	11 6/16	20/16
19:50	12 9/16	19/16

Field measured infiltration rate: 20/16 in per 10 min = 15 feet per day

The adjusted long-term infiltration rate (see "Method for Adjusting Recharge Rates" below) for the Gothenburg at Golf Course site was 2.9 feet per day.

Phelps 9.7

Date of test: May 25, 2010
Location of test hole: N 40 deg 38' 43.5", W 99 deg 31'47.5", Elev 2,455
Depth of hole: 18" below ground surface (bgs)
Soil classification: Damp, dark brown, Sandy SILT (ML)
Installed 4" diameter PVC percometer in hole, filled with water, and recorded depth to water (DTW)

Table 2. Phelps 9.7 Site – Percolation Test Results

Time	DTW (inches below TOC)	Percolation Rate (inches per 10 min)
14:28	0	--
14:40	1 6/16	22/16
14:50	2 5/16	15/16
15:00	3 3/16	14/16
15:10	3 15/16	12/16
15:20	4 10/16	11/16
15:30	5 5/16	11/16
15:40	5 15/16	10/16
15:50	6 9/16	10/16
16:00	7 3/16	10/16

Field measured infiltration rate: 10/16 in per 10 min = 7.5 feet per day

The adjusted long-term infiltration rate (see "Method for Adjusting Recharge Rates" below) for the Phelps 9.7 site was 1.1 feet per day.

Method for Adjusting Recharge Rates

Infiltration rates measured in the field are higher than actual long-term vertical sustainable infiltration rates for the following reasons:

- Small diameter test holes are influenced by horizontal ground water flow that would have a substantially smaller influence on larger scale recharge basins
- Suction at the interface between the water front and the underlying dry soil material draws water into the dry soil, effectively increasing the rate of infiltration

Field measured infiltration rates were adjusted to long-term sustainable infiltration rates based on an analytic approach by Bouwer et al. (1999), which accounts for the considerations listed above.

The following assumptions for variables needed for the Bouwer et al. method were made for the Gothenburg Canal south of Wild Horse Golf Course Site:

- Fillable porosity (i.e., soil porosity not already saturated at the beginning of the field infiltration test) of 0.2 (moderately moist sandy soils)
- Water entry value of -15 cm (fine Sand)
- Radial distance outside 4" diameter PVC infiltrometer of 1 inch

The following assumptions for variables needed for the Bouwer et al. method were made for the Phelps 9.7 Site:

- Fillable porosity (i.e., soil porosity not already saturated at the beginning of the field infiltration test) of 0.2 (moderately moist sandy soils)
- Water entry value of -20 cm (loamy Sand)
- Radial distance outside 4” diameter PVC infiltrometer of 1 inch

References

Bouwer, H., Back, J. T., and Oliver, J.M. 1999. Predicting Infiltration and Ground-Water Mounds for Artificial Recharge. Journal of Hydrologic Engineering. October. Pages 350-357.

Appendix C
Monthly Yield for Configurations Analyzed in Detail

Table C1. Phelps 9.7 Monthly Average Diversions, Yield, and Return Flows Not Credited to Yield

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Diversions (AF per month)	1,887	877	763	756	723	0	0	0	491	413	834	1,857	8,600
Yield at Grand Island (AF per month)	59	260	414	384	402	314	262	397	243	301	232	54	3,321
Return Flows at Grand Island not Credited to Yield (AF per month)	448	299	285	296	289	289	249	28	130	131	208	418	3,070

Table C2. Thirty Mile Monthly Average Diversions, Yield, and Return Flows Not Credited to Yield

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Diversions (AF per month)	2,040	950	824	815	781	0	0	0	532	443	897	2,007	9,289
Yield at Grand Island (AF per month)	75	361	529	434	442	311	258	358	207	264	203	49	3,490
Return Flows at Grand Island not Credited to Yield (AF per month)	636	439	376	376	350	342	233	10	113	146	239	501	3,760

Table C3. Gothenburg Canal South of Golf Course Monthly Average Diversions, Yield, and Return Flows Not Credited to Yield

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Diversions (AF per month)	2,080	969	840	831	675	0	0	0	493	451	913	2,045	9,297
Yield at Grand Island (AF per month)	65	254	381	375	397	328	273	441	288	367	286	70	3,523
Return Flows at Grand Island not Credited to Yield (AF per month)	435	242	222	232	242	248	240	13	134	125	211	446	2,790

Table C4. Gothenburg Canal to B1 Reservoir Monthly Average Diversions, Yield, and Return Flows Not Credited to Yield

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Diversions (AF per month)	0	0	242	234	197	234	228	0	138	142	261	0	1,676
Yield at Grand Island (AF per month)	0	0	0	0	0	222	180	310	0	0	0	0	712
Return Flows at Grand Island not Credited to Yield (AF per month)	0	0	0	0	0	178	169	11	0	0	0	0	358

Table C5. High Ground Water Southwest of Overton Monthly Average Diversions, Yield, and Return Flows Not Credited to Yield

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Diversions (AF per month)	[1]	[1]	[1]	[1]	[1]	[1]	[1]	[1]	[1]	[1]	[1]	[1]	[1]
Yield at Grand Island (AF per month)	0	0	781	775	770	609	471	824	0	0	0	0	4,229
Return Flows at Grand Island not Credited to Yield (AF per month)	0	0	28	28	28	22	17	30	0	0	0	0	153

Note:
[1] Diversions to replace pumped ground water would be made as necessary when available throughout the year; diversions not determined for this analysis