Final

Report of Waste Discharge

Frontier Fertilizer Superfund Site

Prepared for:

EPA

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Acronyms and Abbreviations

μg/L	microgram(s) per liter
DBCP	1,2-dibromo-3-chloropropane
dS/m	deciSiemen(s) per meter
EC	electrical conductivity
EDB	1,2-dibromoethane
EPA	U.S. Environmental Protection Agency
ET_o	reference grass evapotranspiration
GAC	granular activated carbon
INMP	irrigation and nutrient management plan
ISTT	in situ thermal treatment
MCL	maximum contaminant level
mEq/L	milliequivalent(s) per liter
mg/L	milligram(s) per liter
MTBE	methyl tert butyl ether
TCP	1,2,3-trichloropropane
TDS	total dissolved solids
VOC	volatile organic compound
Water Board	California Regional Water Quality Control Board, Central Valley Region

SECTION 1

Introduction

This report of waste discharge for the Frontier Fertilizer Superfund site in Davis, California, presents information on the process that generates treated groundwater and the options for reuse, including specifics on landscape irrigation. The report provides details requested in the California Regional Water Quality Control Board, Central Valley Region (Water Board) memorandum "Request for Additional Information" dated October 22, 2009.

The options for reuse of treated groundwater for irrigation are being investigated by the U.S. Environmental Protection Agency (EPA) and involve agreement from other stakeholders (for example, land owners) before the plan can be finalized. The areas identified for potential irrigation are presented in Table 1 and Figure 1.

TABLE 1
Potential Irrigation Areas
Report of Waste Discharge for Frontier Fertilizer Superfund Site, Davis, California

Potential Irrigation Area	Approximate Acres of Land	Approximate Distance from Treatment Building to Nearest Potential Irrigation Area
Onsite Landscaping at Frontier Fertilizer Superfund Site	8.5	0 to 0.25 mile (depending on onsite irrigation locations)
City of Davis Parks and Greenbelts	35	0.13 mile
Highway Landscaping	2.0	0.48 mile
Railroad Landscaping	2	0.05 mile
Agricultural Fields	> 100	0.62 mile
Private Property Landscaping	2.0	0.56 mile

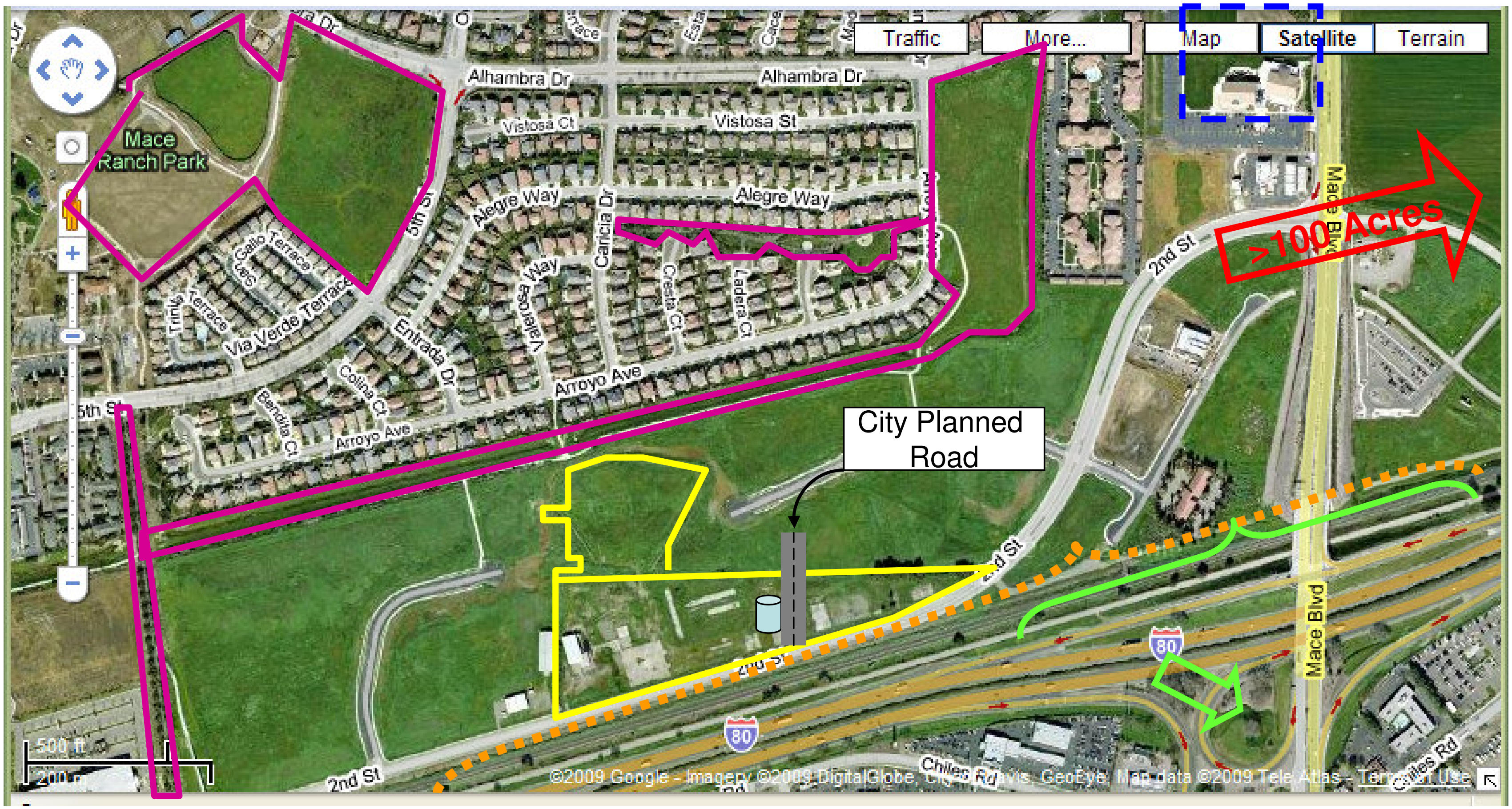
Note: All distances are straight-line and may increase once piping path is known.

Report Organization

The report is organized as follows:

- **Introduction.** Provides background information and potential irrigation areas.
- **Groundwater Treatment Plant.** Summarizes treatment plant operations.
- **Shallow Groundwater Quality.** Provides results of historical monitoring well sampling.
- **Construction Water Tank.** Presents preliminary plan for construction water tank placement and operations.
- **Irrigation Procedures.** Presents irrigation procedures, schedule, and reporting.
- **References.** Provides a list of the references cited.

- **Attachment:** *Plan for Implementing Options for Reuse of Frontier Fertilizer Treated Groundwater* (CH2M HILL, 2009)**.** Provides water balance, water quality, and other evaluations considered to evaluate reuse options for treated groundwater.



City Parks/Greenbelts

Railroad Landscaping

Highway Landscaping, I-80

Private Property Landscaping

Agricultural Fields

Onsite Landscaping

Construction Water Tank

FIGURE 1
Water Reuse Options
Frontier Fertilizer Superfund Site, Davis, California

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SECTION 2

Groundwater Treatment Plant

The onsite groundwater treatment plant extracts volatile organic compound (VOC) contaminated groundwater as part of the site's remedial activities. Groundwater is processed through a granular activated carbon (GAC) system, which removes the VOCs. Treated groundwater is then discharged to the City of Davis sanitary sewer system. Details of the groundwater treatment plant are presented in the *Groundwater Treatment Plant Operations and Maintenance Manual* (CH2M HILL, 2007).

The *Groundwater Treatment Plant Operations and Maintenance Manual* also presents treatment plant operation procedures such as the treatment plant process (Section 1), effluent sampling frequency and requirements (Section 1.9 and Appendix E), and the GAC replacement criteria (Section 7.2). A summary of these sections is presented in the following discussion.

Operations Summary

Groundwater is pumped from 16 extraction wells into the collection manifold, and from there it flows into Collection Tanks 1 and 2 of the treatment system. These tanks have a nominal capacity of 500 gallons each. The two flows are combined downstream, and the combined flow passes through three 2,000-pound GAC vessels in series. Downstream of the third GAC vessel, the treated groundwater is collected in the discharge tank with a nominal capacity of 500 gallons.

The effluent is sampled less than 24-hours before the spent lead GAC vessel is exchanged; at that same time effluent samples are taken from the remaining GAC vessels and from the influent. The lead GAC vessel is exchanged, based on contaminant loading, after about 30 to 60 days in the lead position. The exchange event timing is dependent on the contaminant concentrations detected in monitoring samples and the flow rate. Contaminant and flow rate monitoring performed while GAC vessels are online are used to calculate the mass of adsorbed contaminants in each vessel. When the contaminant load is between 6 to 10 pounds in the lead vessel, it is removed from the process.

After the lead GAC vessel is removed, the vessel that was formerly in the second position is moved to the lead position. The vessel that was formerly in the third position is moved to the second position. A clean vessel is installed in the third position.

Treated Groundwater Quality

Treated groundwater quality is presented in the *Plan for Implementing Options for Reuse of Frontier Fertilizer Treated Groundwater* (provided as an attachment to this report). Table 2 presents the representative treated groundwater quality at Frontier Fertilizer site.

TABLE 2
Representative Water Quality of Treated Groundwater at the Frontier Fertilizer Site
Report of Waste Discharge for Frontier Fertilizer Superfund Site, Davis, California

Constituent	Concentration	Units
Agronomic Water Evaluation – Sunland Analytical, Report dated 6/4/08		
pH	7.04	
EC	2.01	dS/m
TDS	1,286	mg/L
Sodium	204.4	mg/L
	8.9	mEq/L
Calcium	29.74	mg/L
Potassium	0.77	mg/L
Magnesium	124.6	mg/L
Bicarbonate	963.7	mg/L
	15.8	mEq/L
Carbonate	1.0	mg/L
Boron	2.6	mg/L
Chloride	96.46	mg/L
	2.7	mEq/L
Nitrate-N	28.56	mg/L
Phosphate	0.15	mg/L
Sulfate-S	70.47	mg/L
2007 Analytical Results for Effluent		
Copper	2.6–4.9 (average=3.77; number of samples = 3)	µg/L
Manganese	1.3–2 (average = 1.53; number of samples = 3)	µg/L
Nickel	49–59 (average = 53.3; number of samples = 3)	µg/L
Selenium	16–22 (average = 18; number of samples = 9)	µg/L
Zinc	20–44 (average =32; number of samples = 2)	µg/L
Total Chromium	12–28 (average = 17.7; number of samples = 3)	µg/L
MTBE	1–3.9 (average = 2.1; number of samples = 10)	µg/L
1,2 Dibromoethane (EDB)	Non-detect (number of samples = 10); typical detection limit of 0.02	µg/L
1,2 Dibromo-3-Chloropropane (DBCP)	Non-detect (number of samples = 10); typical detection limit 0.02	µg/L
Benzene	Non-detect (number of samples = 10); typical detection limit of 0.5	µg/L
Carbon Tetrachloride	Non-detect (number of samples = 10); typical detection limit of 0.5	µg/L
Chlorobenezene	Non-detect (number of samples = 10); typical detection limit of 0.5	µg/L
1,2-Dichloroethane	Non-detect (number of samples = 10); typical detection limit of 0.5	µg/L

TABLE 2
Representative Water Quality of Treated Groundwater at the Frontier Fertilizer Site
Report of Waste Discharge for Frontier Fertilizer Superfund Site, Davis, California

Constituent	Concentration	Units
1,2-Dichloropropane	Non-detect (number of samples = 10); typical detection limit of 0.5	µg/L
1,3-Dichloropropane	Non-detect (number of samples = 10)	µg/L
1,2,3-Trichloropropane (TCP)	Non-detect (number of samples = 10); typical detection limit of 0.5	µg/L
Standard analytes list – EPA Method 524.2 (other than those listed above)	Non-detect (number of samples = 10); typical detection limits range from 0.5 to 4.0 depending on analyte	µg/L

Notes:
µg/L = microgram(s) per liter
dS/m = deciSiemen(s) per meter
EC = electrical conductivity
mEq/L = milliequivalent(s) per liter
mg/L = milligram(s) per liter
MTBE = methyl tert butyl ether
TDS = total dissolved solids

Groundwater Treatment Plant Performance Monitoring

Groundwater treatment plant performance monitoring includes collecting samples for chemical analysis prior to each GAC vessel exchange. Baseline samples will be collected and analyzed prior to beginning reuse of the treated groundwater. Performance monitoring will continue when the treated groundwater is being reused. In addition, if treated groundwater is being reused during the planned source zone remediation, in situ thermal treatment (ISTT), the monitoring frequency will be increased during the ISTT operation. Planned treatment system effluent sampling methods, analyses, and frequencies are identified in Table 3.

If an analyte is detected above its California Maximum Contaminant Level (MCL) or if TCP is detected above the California Department of Public Health notification level, the system effluent will be re-sampled within 48 hours to check the prior sample analysis result and Water Board staff will be notified. If the re-sample measurement verifies the routine sample measurement, reuse will be discontinued until the cause for the elevated measurement can be identified and corrected.

TABLE 3
Monitoring Frequency for Groundwater Treatment System Effluent
Report of Waste Discharge for Frontier Fertilizer Superfund Site, Davis, California

Method:	**EPA 524.2 SIM**	**EPA 524.2**	**EPA 504.1 or EPA 524.2 SIM**
Analytes:	TCP	standard analyte list	EDB, DBCP
Method Reporting Limit:	Typically 0.005 µg/L*	typically 0.5 µg/L	typically 0.02 µg/L
Monitoring Period	**Sample Collection Frequency**		
Baseline (prior to reuse)	Once at 2 weeks, 1 week, and less than 24 hours prior to a GAC vessel exchange.	Concurrent with routine monitoring (less than 24 hours prior to a GAC vessel exchange)	
Reuse (during ISTT)	Monthly for the first 6 months, once every 2 months thereafter	Concurrent with routine monitoring (less than 24 hours prior to a GAC vessel exchange)	
Reuse (without concurrent ISTT)	Concurrent with routine monitoring (less than 24 hours prior to a GAC vessel exchange)		

*TCP California Department of Public Health Notification Level.

Note:
Routine sample analysis turnaround-time is 21 days and re-sample analysis turnaround time will be 3 days.

SECTION 3

Shallow Groundwater Quality

Kleinfelder collected mineral samples from five monitoring wells at the Frontier Fertilizer site for three rounds in late 2008 as field work associated with the Target store development (*Field Report, Proposed Second Street Crossing, Retail Development Target Store T-2455, Davis, California,* Kleinfelder, 2009); Table 4 presents shallow (S-1 zone) general mineral groundwater quality at the Frontier Fertilizer site.

TABLE 4
Representative General Mineral Water Quality of Shallow Groundwater at the Frontier Fertilizer Site
Report of Waste Discharge for Frontier Fertilizer Superfund Site, Davis, California

Constituent	Concentration	Units
Chloride	13 – 120 (average = 95; total samples = 15)	mg/L
Nitrate	4.3 – 20 (average = 11; total samples = 15)	mg/L
Sulfate	56 – 320 (average = 214; total samples = 15)	mg/L
Calcium	19 – 46 (average = 36; total samples = 15)	mg/L
Iron	0.076 – 4 (average = 0.53; total samples = 15)	mg/L
Magnesium	60 – 140 (average = 114; total samples = 15)	mg/L
Potassium	1.7 – 5.3 (average = 2.5; total samples = 15)	mg/L
Sodium	96 – 240 (average = 193; total samples = 15)	mg/L
Bicarbonate	430 – 700 (average = 610; total samples = 15)	mg/L
Carbonate	Non-detect (number of samples = 21); typical detection limit of 10	mg/L

SECTION 4

Construction Water Tank

The construction water tank will be accessible from a turn-out on Second Street (Figure 1). Facilities would include a water tank and J-stand for truck filling at the Frontier Fertilizer site. Access to a locked enclosure will be made available to permitted users, who would sign the necessary paperwork ensuring appropriate use of the water. This water will be used for dust control during construction and road maintenance.

SECTION 5

Irrigation Procedures

This section describes Frontier Fertilizer site irrigation system components, normal irrigation schedule, schedule adjustment in response to rain events, system leak identification, and measures to prevent runoff to surface water.

Irrigation System Components

The specific elements of the irrigation systems will vary depending on the use area. However, all irrigation use areas will have the following common elements:

- **Irrigation Regulating Tank—**This tank will buffer flows from the groundwater treatment system before pumping out to the irrigation use areas. Water levels in the tank will fluctuate depending on the continuous inflow of treated water and the periodic outflow to the irrigation use areas. When water levels in the tank reach the level of an overflow pipe near the top of the regulating tank, treated water will flow by gravity back to the sewer discharge. An irrigation pump will remove water from a valved outlet near the bottom of the regulating tank. Sizing of this tank will depend on an evaluation of supply/demand curves for the planned irrigation use areas, available space onsite, and tank cost.

- **Irrigation Pump—**This pump will transfer water from the irrigation regulating tank out to the use areas and will provide the necessary irrigation operating pressure. The pump or pumps will be sized according to the flow and pressure requirements of the final connected irrigation use areas.

- **Irrigation Controller and Sensors—**The irrigation controller will operate the irrigation pump based on an operator-specified irrigation schedule. System flow rate, operating pressure, and rainfall shutoff sensors will be wired into the irrigation controller to provide the necessary feedback to the pumping system that will allow pumping shutdown in the event of a system water leak or significant rainfall.

- **Buried Pipelines and Control Valves—**All irrigation piping between the irrigation pump station and irrigation use area will be buried and will follow state and county codes for pipeline identification and cross-connection control. Automated irrigation control valves will be installed for each distinct irrigation operational zone. Control wiring for each control valve will be routed within the buried pipeline trenches.

- **Backflow Prevention—**For irrigation areas that will continue receiving water from sources other than the Frontier Fertilizer reclaimed water, backflow prevention systems will be installed and will follow state and county codes.

The following irrigation components will be specific to the Onsite Landscaping at Frontier Fertilizer Superfund Site, City of Davis Parks and Greenbelts, and Highway, Railroad, and Private Property Landscaping:

- **Aboveground Irrigation Application System—**Irrigation systems will be comprised of micro-spray, drip, and/or sprinkler application systems. Application systems and irrigation schedules will be selected and managed to prevent runoff of irrigation water.

The following irrigation components will be specific to the Agricultural Fields:

- **Aboveground Irrigation Application System—**Nearby fields are currently flood irrigated and would continue with this water management method. Field grading, borders, and supply piping/ditching will be modified as needed to ensure efficient water delivery and to prevent runoff of reclaimed water.
- **Tailwater Collection and Recirculation System—**Any fields used for water irrigation with treated groundwater will have berms and ditches maintained around the use area to collect all tailwater. A tailwater sump and pumping system with return flow piping will also be installed to return any collected water back to the head of the field.

Normal Irrigation Schedule

An irrigation and nutrient management plan (INMP) will be prepared for each use area prior to application of treated groundwater. This plan will specify agronomic rates for water and nitrogen loading of each site based on soil and vegetation conditions, and will outline normal irrigation schedules based on average climate conditions and irrigation application system design and operational constraints. Following a typical outline prepared for recycled water projects, the INMP for each use area will include the following report elements:

- Introduction
- Reuse Site Characteristics
  - Soils
  - Site Vegetation and Management
  - Irrigation System
- Irrigation Water Quality
  - Nitrogen
  - Salinity
- Irrigation Water Management
  - Irrigation Water Budget
    - Climate
    - Crop and Soil Characteristics
    - Irrigation System Characteristics
    - Irrigation Water Requirements
  - Irrigation Scheduling
    - Average Year Irrigation Schedule
    - Planned Irrigation Scheduling Procedures

- Nutrient Management
  - Required Nutrients
  - Nutrient Sources
  - Nutrient Budget
    - Nutrients in Reclaimed Water
    - Nutrients in Other Sources
    - Supplemental Fertilization
  - Management Practices to Manage Nutrient Loading
- Monitoring and Reporting
  - Recordkeeping
  - Recycled Water Use Area Monitoring
  - Groundwater Monitoring
  - Annual Report

Each INMP will address any irrigation limitations imposed by the landowner or regulatory agencies and any controls or safeguards unique to the irrigation area. It will also include a summary of feedback controls and inspection schedules for the irrigation area.

Two possible irrigation management schemes for the onsite landscaping at the Frontier Fertilizer site were presented in the *Plan for Implementing Options for Reuse of Frontier Fertilizer Treated Groundwater*. A similar level of detail will be presented for the selected vegetation and management at this site and all other reuse sites in the INMPs.

Irrigation and nutrient loading rates for all sites will be developed to allow operation within agronomic rate limitations for hydraulic and nutrient loading on an average year basis. Water Board staff will review and provide concurrence or comment on the specific INMP(s) prior to irrigating the subject areas.

Schedule Adjustment for Weather and Rain Events

The average year water balances presented in the INMP will be based on average historic values of reference grass evapotranspiration (ET_o) and precipitation. Actual ET_o and precipitation may be higher or lower than the historical average; therefore, actual irrigation water requirements will differ somewhat. To ensure that an appropriate amount of irrigation water is applied to the use areas in response to actual climate conditions, the procedures identified below will be followed.

(1) On a weekly basis, ET_o data will be evaluated from the CIMIS web site for the nearby Davis station. Daily ET_o variance will be determined for the preceding week to compare current ET_o with historical conditions. The variance report will also provide the average year projection for the next monitoring period (for example, 1 to 2 weeks). Based on variance and ET_o predicted for the following monitoring period, either frequency or duration of irrigation might be adjusted.

(2) Visual observations of the use areas will also be made to adjust irrigation schedules. On turfgrass areas, brown spots in the landscape or salt crust on the soil surface could indicate that insufficient water is being applied. Likewise, ponded water, disease, or moss accumulation could indicate that too much water is being applied.

Visual indicators, in conjunction with ET_o variance, will be used when appropriate to make adjustments to the irrigation regime.

Soil moisture will be evaluated using the texture feel method for each use area on a weekly basis for the first year to aid in irrigation scheduling procedure refinement. Soil moisture should generally be managed between an upper limit of field capacity and a lower limit of the soil moisture at management-allowed depletion.

System Leak Identification

System leak identification will be accomplished both automatically through the irrigation controller for failsafe system control and manually by system inspection and regular review of irrigation operational data records.

Automatic Operations—The irrigation controller will shut down the irrigation pump in the event of a significant water leak. System shutdown will occur in response to low system pressure measured downstream of the pump or metered flow being recorded outside the anticipated flow range. Restarting of the irrigation pump will require manual control to reset the event alarm, requiring operations personnel to investigate the cause of system shutdown before water delivery continues.

Manual Operations—Operations personnel will perform regular monthly inspections for visual signs of leaks including wet or saturated ground around irrigation system components. At least annually, irrigation flow meter records will be compared to projected irrigation volume deliveries based on irrigation operations times and system flow demands. Flow meters will be recalibrated as needed.

Measures to Prevent Runoff to Surface Water

For the Onsite Landscaping at Frontier Fertilizer Superfund Site, City of Davis Parks and Greenbelts, and Highway, Railroad, and Private Property Landscaping, irrigation application systems will be designed and operated to apply water at rates less than the soil infiltration rates and to prevent runoff of irrigation water.

For irrigation to the Agricultural Fields, which are currently flood irrigated, a tailwater recovery and recirculation system will be installed and operated during all times under which reclaimed water is being irrigated to the site.

Reporting

Reporting on the operation of the irrigation system will be quarterly. The report will include irrigated quantities, schedules, and other pertinent information regarding system operations.

SECTION 6

References

CH2M HILL. 2009. *Plan for Implementing Options for Reuse of Frontier Fertilizer Treated Groundwater.* Technical memorandum prepared for U.S. Environmental Protection Agency. September 9.

CH2M HILL. 2007. *Groundwater Treatment Plant Operations and Maintenance Manual Frontier Fertilizer Superfund Site.* Prepared for U.S. Environmental Protection Agency. May.

Kleinfelder. 2009. *Field Report, Proposed Second Street Crossing, Retail Development Target Store T-2455, Davis, California.* May 20.

Regional Water Quality Control Board. 2009. Request for Additional Information, Memorandum. October.

Attachment
Plan for Implementing Options for Reuse of Frontier Fertilizer Treated Groundwater

Plan for Implementing Options for Reuse of Frontier Fertilizer Treated Groundwater

PREPARED FOR:	Bonnie Arthur/U.S. Environmental Protection Agency, Region 9
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CONTRACT/TO/PN:	EPA Contract No. EP-S9-08-04/Task Order 008/384792.PJ.01
DATE:	September 9, 2009

1.0 Summary and Recommendations

Cleanup of the Frontier Fertilizer Superfund Site (Site) currently entails extracting and treating groundwater, then discharging the reclaimed water to the sanitary sewer. The budget available for Site cleanup is reduced by escalating costs to discharge to City of Davis sewerage system, reduced demand on City of Davis limited potable water resources, and the need for sustainable reuse of treated groundwater prompted investigation of options for reuse of the treated groundwater. This memorandum evaluates potential reuse options for the treated groundwater and provides a detailed evaluation of the options for onsite irrigation.

The following reuse options have been identified and warrant further study (in the approximate order of feasibility):

- Irrigation of Onsite Landscaping
- Distribution of Water for Dust Control
- Irrigation of Highway Landscaping
- Irrigation of Nearby Agricultural Fields
- Irrigation of City of Davis Parks and Greenbelts or private property landscaping

Onsite reuse options that were discussed but show the least promise, because of the effect on control of contaminated groundwater, include drainfields, infiltration basins, direct injection into groundwater, and seasonal storage in combination with other end uses. Recommendations for next steps in pursuing each of these options are provided in this memorandum.

An assessment of treated groundwater suitability for irrigation uses concluded that the primary limitations were the moderate salinity and elevated nitrate concentrations in the reclaimed water. This assessment also concluded that the water is generally suitable for landscape irrigation as long as appropriate measures are taken to exclude particularly salt-sensitive species, maintain appropriate leaching fractions, and prevent overspray of water onto foliage, where plant appearance is important.

One of the primary limitations for reuse of the recycled water onsite is the potential impact to the groundwater plume capture within the pump-and-treat operations. Before an onsite irrigation alternative is finalized, an assessment of the plume capture under current conditions and the ultimate operational objectives for the Site should be reviewed to determine whether any additional onsite recharge would be acceptable.

Two onsite irrigation alternatives were developed: (1) deficit irrigated mixed landscape and (2) fully irrigated poplar tree stand. With the 8.5 acres of land available for landscaping at the Site, irrigation demands ranged from 4.5 to 8.6 million gallons per year (MG/yr), compared with the 35 MG/yr of reclaimed water produced. Irrigation water demand varies seasonally, and peak demand occurs in July. For each landscaping scenario, there is a period of about 5 months (November through March) during which no irrigation would be applied. The limitations on the amount of irrigation water that can be applied are driven by resulting recharge to groundwater for one scenario and agronomic loading of nitrogen for the other scenario.

Sewer charges over the next 10 years are projected at about $3 million. Projected present worth cost savings in avoided sewer charges range from $280,000 to $535,000 over the next 10 years for the two onsite irrigation alternatives. In order to evaluate the cost-benefit of these reuse options, budgetary cost estimates are needed for the capital and operations and maintenance (O&M) expenses required to implement these options.

Landscape irrigation appears to be a viable alternative, alone or in combination with other alternatives, for reuse of reclaimed water at the Site. Several ancillary benefits aside from the potential cost savings include the enhanced Site aesthetics and the reduced impact on the City of Davis sewer collection system and wastewater treatment plant. This alternative should be detailed further to establish the implementation approaches and to develop budgetary cost estimates.

2.0 Pump and Treat Water Production

Groundwater underneath the Site is impacted by former pesticide and fertilizer operations. The treatment system extracts groundwater containing pesticides, pumps it through granular activated carbon, and discharges the reclaimed water to the City of Davis sanitary sewer. The treated water is required to have no detectable levels of pesticides and is monitored routinely as a condition of the City-issued discharge permit.

Treated water production at the Site is approximately 3 MG per month, or 35 MG/yr. Production rates have varied from about 2.5 to 3.5 MG per month with the highest production rates occurring during the months of January through May (Table 1).

At the FY 2009-2010 industrial sewer rate of $4.1834 per 100 cubic feet or about $5,590 per MG, the annual cost of sewer discharge is approximately $198,000. However, this rate is scheduled to increase by 58 percent over the next 6 years (Foresight Consulting, 2007).

TABLE 1
Average Monthly Treated Water Flows from January 2005 to November 2008
Plan for Implementing Options for Reuse of Frontier Fertilizer Treated Groundwater, Frontier Fertilizer Superfund Site, Davis, California

Month	Average Flow (gallons)
January	3,286,598
February	3,066,049
March	3,475,494
April	3,294,128
May	3,262,980
June	2,916,423
July	2,835,477
August	2,604,336
September	2,473,054
October	2,492,073
November	2,705,174
December	2,971,484
Total	**35,383,269**

3.0 Water Reuse Options

Several possible options for treated groundwater reuse have been discussed in meetings with the Regional Water Quality Control Board (RWQCB) and the U.S. Environmental Protection Agency (EPA). These options are briefly discussed in the following sections. Recommendations for further action, included in Table 2, have the highest potential for being implementable and are most cost effective in reducing the long-term costs of water reuse.

TABLE 2
Recommended Actions for Further Refinement of Water Reuse Options
Plan for Implementing Options for Reuse of Frontier Fertilizer Treated Groundwater, Frontier Fertilizer Superfund Site, Davis, California

Water Reuse Option	Recommended Actions
Distribution of Water for Dust Control	Contact local construction contractors, street sweeping operations, and the Yolo County Central Landfill to survey the interest and estimate the amount of potential water reuse. If cost savings from the estimated amount of water reuse could offset the cost of installing the truck-filling tank and managing the permitting aspects of this use, then further design and implementation could be pursued.

TABLE 2
Recommended Actions for Further Refinement of Water Reuse Options
Plan for Implementing Options for Reuse of Frontier Fertilizer Treated Groundwater, Frontier Fertilizer Superfund Site, Davis, California

Water Reuse Option	Recommended Actions
Irrigation of City of Davis Parks and Greenbelts	A potentially viable option. However, significant public involvement would be required and the risks are higher than for other alternatives. Before pursuing this alternative further, all other viable alternatives should first be ruled out.
Irrigation of Highway Landscaping	Contact Caltrans to determine whether there is interest in this treated groundwater. If so, obtain landscape irrigation plans for the areas nearest the Site to evaluate how much irrigated area is available and the potential water use for these areas. Preliminary cost estimates and water budgets should then be prepared to determine whether this approach would be cost effective.
Irrigation of Nearby Agricultural Fields	Contact the farmers operating the nearest irrigated lands to the east of the facility. If there is interest in the water source, terms of the agreements could be discussed and preliminary cost estimates and water budgets could be prepared to determine whether this approach would be cost effective.
Onsite Drainfields, Infiltration Basins, or Direct Injection into Groundwater	Not recommended at this time.
Irrigation of Onsite Landscaping	This alternative holds promise and is discussed in detail in this memorandum. After selecting a scenario and further detailing how this project would be implemented, a budget-level capital and O&M cost estimate is needed to evaluate the cost-benefit of pursuing this option.
Seasonal Storage in Combination with Other End Uses	Not recommended at this time.

3.1 Distribution of Water for Dust Control

Water could be made available to construction and industrial operations that are currently using potable water for dust control. There is an existing waiver for low-threat discharges (R5-2008-0182 under Discharge Type 11 – Construction) that makes this type of use relatively simple to permit. A simple Report of Waste Discharge describing the water source; water quality; and the proposed use, facilities, and application areas would need to be prepared for RWQCB approval. A Title 22 Engineering Report may also be required for submittal to the California Department of Public Health Services. However, since this is not recycled water, this requirement might be waived.

Facilities required for this use could be as simple as a water tank and J-stand for truck filling at the Site. Access to a locked enclosure could be made available to permitted users, who would sign the necessary paperwork ensuring appropriate use of the water. Possible use of this water would be construction and road maintenance dust control.

3.2 Irrigation of City of Davis Parks and Greenbelts

The City of Davis Mace Ranch Neighborhood Park is approximately 0.5 mile to the northwest of the Site and is a potential irrigation reuse area for the reclaimed water. Typical Waste Discharge Requirements (WDRs) for this type of application would stipulate that reclaimed water be applied within hydraulic and nutrient agronomic loading rates and that no runoff or ponding of water occurs during irrigation. Title 22 requirements for cross-connection control, backflow prevention, restriction of spray application near public drinking facilities, and scheduling irrigation to minimize public contact would also need to be followed. Non-technical issues such as local public health risk perception could also be a significant factor and would necessitate an active public education and involvement program. Potential barriers to implementing this type of project could include the cost of conveyance to the parks and retrofitting irrigation systems as well as the costs for permitting and public participation programs.

3.3 Irrigation of Highway Landscaping

The Mace Boulevard interchange on Interstate 80 (I-80) is approximately 0.5 mile to the east of the Site and is a potential irrigation reuse area for the reclaimed water. Permit requirements for irrigation reuse in this type of area would be similar to those described above for irrigation to City parks. However, the level of public involvement and potential public access would be far lower because of the limited public contact within this type of land use.

3.4 Irrigation of Nearby Agricultural Fields

There are several flood irrigated fields to the east of the Site starting about 0.5 mile to the east. Most of these lands are currently flood irrigated but cropping is unknown. The largest issue with this type of application is the need for controlling and recycling all tailwater to eliminate any surface water discharge. Most municipalities and industries that operate this type of reuse own the land and contract resources to operate their irrigation facilities to maintain appropriate control of the water and limit their risk. Due to the high cost of land in the area, the only cost effective solution for this type of application would be if one of the nearest farmers were interested in the new water source and were willing to closely control tailwater recycling under permit conditions in exchange for the new water source.

3.5 Drainfields, Infiltration Basins, or Direct Injection into Groundwater

The primary requirements for this type of project would be that (1) underlying groundwater is similar quality to the discharge water and that no further degradation is occurring, (2) the discharge would not mobilize other contaminants, and (3) infiltration areas do not interfere with the collection of contaminated groundwater within the existing groundwater extraction system. Initial investigation of this alternative revealed that infiltration at most locations within the existing Frontier Fertilizer property, with the possible exception of the eastern portion, would be drawn into the pump-and-treat groundwater capture zone and could impact the collection of contaminants.

3.6 Irrigation of Onsite Landscaping

Until pesticide source zone treatment is completed, there are approximately 8.5 acres of area within the Frontier Fertilizer Site fenced boundary that could be landscaped using treated groundwater. With restricted Site access, this approach would have a low risk and would be relatively easy to permit. WDRs would stipulate that reclaimed water will be applied within hydraulic and nutrient agronomic loading rates and that no runoff or ponding of water will occur during irrigation. Landscaping vegetation and irrigation systems could take several different forms, depending upon the multiple Site objectives. However, one of the primary issues to address is the potential for increasing recharge to groundwater within the plume capture zone and the possible impact on capture of contaminants.

3.7 Seasonal Storage in Combination with Other End Uses

Because of the relatively constant production rates of reclaimed water throughout the year and the natural seasonality of irrigation demands primarily during the spring, summer, and fall months, seasonal water storage would be required to attain full reuse of the reclaimed water with any of the irrigation alternatives. Based on order of magnitude capital costs for developing the least-cost storage with lined basins ($45,000 to $75,000 per MG), and the need to oversize ponds for additional winter precipitation capture (estimated 50 percent upsizing), the payback period for storage would be around 14 to 23 years, not including the additional costs for subsequent reuse of the water. These initial calculations suggest that seasonal storage is not likely to prove cost effective.

4.0 Groundwater Plume Capture

With plume capture and on-going Site remediation as the primary objectives of Site operations, any proposal for onsite irrigation reuse must be capable of operating without detriment to those activities. Evaluation of the existing groundwater model is discussed below.

The groundwater model described in the technical memorandum Frontier Fertilizer Groundwater Model Update and Extraction Wellfield Plan (CH2M HILL, 2003) was used to investigate the feasibility of using reclaimed water for onsite irrigation. The initial analysis examined only the impact of additional recharge on the position of the water table. This analysis concluded that the shallow aquifer system could accept significant additional recharge. Because additional recharge could raise the water table to the land surface, depending on the area irrigated, the amount of water applied, and local hydraulic properties, a second stage of analysis considered the impact of the additional recharge on the remediation system's ability to hydraulically control contaminated groundwater.

During the second stage of analysis, the additional recharge applied during the first stage resulted in the simulated loss of hydraulic control. Reducing the simulated recharge rate to the original calibrated values indicated that complete hydraulic capture is not achieved for a small portion of the plume, even with no added recharge water. This result was compared with field observations, which indicate that for part of the year, downward head differences are observed at some vertical well pairs. The second stage of analysis concluded that because the plume is not completely hydraulically controlled prior to the addition of recharge water, any additional recharge will result in further loss of hydraulic control.

Analysis of groundwater chemical monitoring results indicated that concentrations of the primary chemicals of concern are declining in all three zones, S-1, S-2, and A-1. The contaminated groundwater extraction system collects water from the top two zones, S-1 and S-2. Because concentrations in the lower A-1 zone are also declining, the collection system appears to be removing contaminants before they migrate downward.

The results of this analysis suggest that some amount of treated groundwater infiltration from onsite reuse may not reduce the effectiveness of the contaminated groundwater control. A balance between evapotranspiration, and rain and irrigation would be necessary to optimize onsite reuse. Groundwater monitoring would provide feedback necessary to refine the balance.

5.0 Treated Groundwater Quality

The treated groundwater is monitored to evaluate treatment process performance and would continue to be monitored under any reuse scenario. It is anticipated that additional monitoring of chemical characteristics that are critical to a specific reuse application would be implemented, since current monitoring focuses on volatile organic chemicals. Initially, the frequency of monitoring of parameters that affect reuse options would be established to determine variations during an annual cycle. Once annual variations in the parameters are documented, the frequency of monitoring would be reduced.

Treated groundwater quality is an important consideration in determining the compatibility of the water source for specific irrigation uses and Site limitations. Representative composition of treated groundwater at the Site is provided in Table 3.

TABLE 3
Representative Water Quality of Treated Groundwater at the Frontier Fertilizer Site
Plan for Implementing Options for Reuse of Frontier Fertilizer Treated Groundwater, Frontier Fertilizer Superfund Site, Davis, California

Constituent	Concentration	Units
Agronomic Water Evaluation – Sunland Analytical, Report dated 6/4/08		
pH	7.04	
EC	2.01	dS/m
TDS	1,286	mg/L
Sodium	204.4	mg/L
	8.9	meq/L
Calcium	29.74	mg/L
Potassium	0.77	mg/L
Magnesium	124.6	mg/L
Bicarbonate	963.7	mg/L
	15.8	meq/L
Carbonate	1.0	mg/L
Boron	2.6	mg/L

TABLE 3
Representative Water Quality of Treated Groundwater at the Frontier Fertilizer Site
Plan for Implementing Options for Reuse of Frontier Fertilizer Treated Groundwater, Frontier Fertilizer Superfund Site, Davis, California

Constituent	Concentration	Units
Chloride	96.46 2.7	mg/L meq/L
Nitrate-N	28.56	mg/L
Phosphate	0.15	mg/L
Sulfate-S	70.47	mg/L
2007 Analytical Results for Effluent		
Copper	2.6–4.9 (average=3.77)	µg/L
Manganese	1.3–2 (average = 1.53)	µg/L
Nickel	49–59 (average = 53.3)	µg/L
Selenium	16–22 (average = 18)	µg/L
Zinc	20–44 (average =32)	µg/L
Total Chromium	12–28 (average = 17.7)	µg/L
MTBE	1–3.9 (average = 2.1)	µg/L

µg/L = microgram(s) per liter
dS/m = deciSiemen(s) per meter
EC = electrical conductivity
meq/L = milliequivalent(s) per liter
mg/L = milligram(s) per liter
MTBE = methyl tert butyl ether
TDS = total dissolved solids

Water quality of treated groundwater was evaluated for potential irrigation and crop management problems resulting from salinity, specific ion toxicity, infiltration hazard, and nutrient loading. Each of these is briefly discussed below.

5.1 Salinity

EC and TDS are commonly used indicators of salinity in irrigation water and are linearly related within normal salinity levels for irrigation (TDS in mg/L ≈ 640 x EC in dS/m). Salinity levels in the reclaimed water (2.0 dS/m and 1,286 mg/L TDS) could pose slight to moderate limitations for use.

A survey of golf courses in the Santa Barbara area (CH2M HILL, 2009) revealed that two golf courses and multiple City parks, schools, and residential areas have been using recycled water produced by the City of Santa Barbara with salinity levels (1.7 dS/m and 1,127 mg/L TDS) similar to that of the Frontier Fertilizer treated groundwater. For golf courses using the City of Santa Barbara recycled water, specific management measures to avoid vegetation impacts have included dual piping of potable water to the salt sensitive greens (*Poa annua* dominated) and modifying irrigation systems to prevent overspray of recycled water onto sensitive tree and shrub foliage. As long as irrigation water does not spray over the foliage, these courses have not had problems with recycled water impacts to vegetation.

Based on the moderate salinity levels and demonstrated experience managing similar quality water for recycled water irrigation within urban landscape irrigation applications, it appears that the **Frontier Fertilizer water should be suitable for landscape irrigation applications as long as appropriate measures are taken to exclude particularly salt-sensitive species, maintain appropriate leaching fractions, and to prevent overspray of water onto foliage, where plant appearance is important.**

5.2 Specific Ion Problems

Certain individual constituents in water may cause toxicity to sensitive plants, induce soil fertility problems, or create aesthetic problems. These constituents commonly include sodium, chloride, boron, and bicarbonate. While chloride levels are below levels of concern even for sensitive species, concentrations of sodium are at levels that may present problems to plant performance, especially if using sprinkler irrigation with overspray onto plant leaves. Sodium toxicity can occur at levels above 3 meq/L; and sodium is present in treated groundwater at a concentration of nearly 9 meq/L (204 mg/L). Sodium toxicity symptoms could include leaf burn, scorch, and necrosis along the outside edges of leaves, beginning on older leaves. In addition, boron levels (2.6 mg/L) may be sufficiently high to cause toxicity in sensitive plants. Lastly, bicarbonate occurs at levels that can cause potential salt residue accumulation on plant leaves with overspray and potential fertility issues by inducing calcium deficiency. However, this issue can be managed by preventing overspray and possibly amending soils with gypsum as necessary.

For landscape irrigation applications, irrigation of this water should be possible to manage without significant plant health impacts as discussed in the salinity section above. However, some special considerations may be required for irrigation system design and soil management.

5.3 Infiltration Hazard

High sodium content in fine-textured soils can cause destruction of soil structure, dispersion and reduced ability for water to infiltrate the soil. The sodium hazard is more severe when sodium is the dominant ion in solution (i.e., calcium and magnesium levels are low) and electrical conductivity is low. The sodium hazard is predicted by evaluating the sodium adsorption ratio (SAR), which is defined in irrigation water as follows:

$$SAR = \frac{[Na]}{\sqrt{\frac{([Ca]+[Mg])}{2}}}$$

where SAR = Sodium adsorption ratio,
[Na], [Ca], and [Mg] are in meq/L.

Calcium and magnesium levels are sufficiently high that no soil infiltration problems associated with high levels of sodium in the treated water are expected, if the water is used for landscape irrigation, as shown on Figure 1.

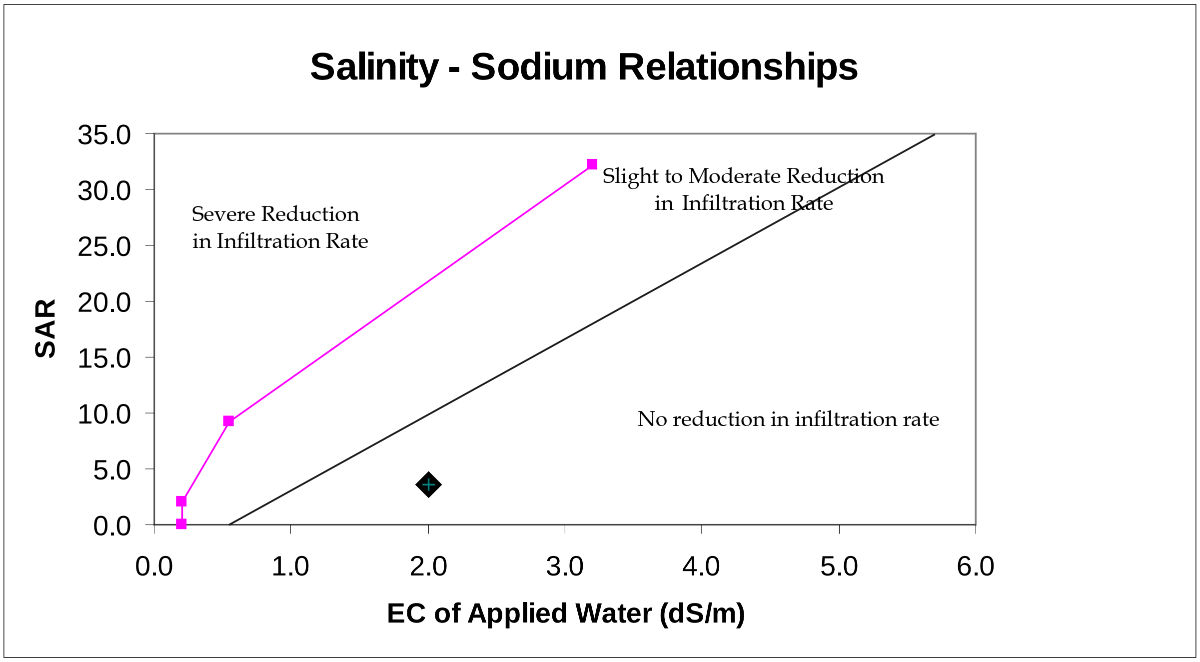

FIGURE 1
Infiltration Reduction Risk Associated with SAR and Salinity in Treated Groundwater at the Frontier Fertilizer Site
(Diamond indicates chemistry of treated groundwater. No reduction in infiltration is expected)

5.4 Nitrogen Loading

Nitrogen levels in groundwater are fairly high, and nutrient loading rates need to be assessed to determine potential nutrient-driven loading limitations. WDRs will typically require nitrogen to be applied within agronomic rates for the particular crop under irrigation. Assuming ammonia-N levels in the groundwater are insignificant and that nitrate-N composes the bulk of total nitrogen in the water, approximately 78 pounds per acre (lb/ac) of nitrogen would be delivered with each foot (12 inches) of irrigation depth.

A comparison of agronomic nitrogen loading rates for several potential crop/vegetation types is presented in Table 4 along with the maximum recycled water irrigation depths based on nitrogen loading limitations. **For a landscape of cool season turfgrass and mixed ornamental trees and shrubs, the suggested maximum nitrogen loading rates are about 175 lb/ac/yr. At this rate, reclaimed water should not be irrigated in excess of about 27 inches per year (in/yr) (2.25 acre-feet per acre per year [ac-ft/ac/yr]). For a mature stand of poplar trees, the nitrogen loading rates increase to 240 lb/ac/yr and irrigation up to 37 in/yr (3.1 ac-ft/ac/yr).**

TABLE 4
Agronomic Nitrogen Loading Rates and Maximum Irrigation Depths
Plan for Implementing Options for Reuse of Frontier Fertilizer Treated Groundwater, Frontier Fertilizer Superfund Site, Davis, California

Crop/Vegetation Type	Agronomic Nitrogen Loading Rates (lb/ac/yr)	Maximum Recycled Water Irrigation Depth (in/yr)[a]
Turfgrass	132 to 176[b]	20 to 27
Ornamental Trees and Shrubs—deciduous and narrow leaf evergreens	132 to 264[c]	20 to 41
Ornamental Trees and Shrubs—broad leaf evergreens	66 to 132[c]	10 to 20
Irrigated Pasture	200 to 300[d]	31 to 46
Poplar Trees	100 to 240[e]	15 to 37

[a] The allowable irrigation depths are based on a total nitrogen content of 28.6 mg/L and assume no volatilization or denitrification losses of applied nitrogen.
[b] Based on 3 to 4 applications per year of 44 lb/ac per application for “Central Valley, North and Central Coast” locations (UCANR, 2002). Four applications are recommended for cool season grasses.
[c] The low rate is for average conditions, and the high rate is for plants in poor health (Smith, 1978).
[d] This range is for maximum yields in Northeast California and Southeast Oregon. Higher values may be recommended in locations where yield potential is higher, and lower values may be recommended where yields are lower or where rates are based on an economic return analysis incorporating nitrogen fertilizer costs (UCCE, 1993).
[e] Range is for poplar tree plantations ranging from 1 to 5 years and greater and assuming 50 percent cover of interrow grass in the first year (WDE, 1999).

6.0 Site Soil Properties

Characteristics of the soils underlying the Site were briefly reviewed to identify any obvious restrictions for irrigation or vegetation establishment. A single soil map unit underlies the Site: Sycamore silt loam, drained (USDA-NRCS, 2009). Relevant chemical and physical characteristics of this soil are as follows:

- Texture: silt loam from a depth of 0 to 60 inches
- 80 inches to a restrictive layer
- Somewhat poorly drained
- Moderately high to high saturated hydraulic conductivity (0.57 to 1.98 inches per hour)
- Available water capacity of 0.19 inch per inch

Although there are no apparent rooting or irrigation limitations from the soil survey data, soil properties have likely been modified in some portions of the property around buildings and foundations and under heavily trafficked areas. **An onsite soil investigation would be needed to facilitate the design of any onsite irrigation reuse application.**

7.0 Existing Groundwater Recharge Rates

Existing groundwater recharge rates are important for the calibration of groundwater models and for estimating potential future impacts to groundwater capture in response to irrigation over the plume area.

The existing vegetation at the Site consists primarily of annual grasses that senesce and die, turning brown in the late-spring of each year. This type of vegetation has limited water use potential, allowing more precipitation recharge to groundwater in this climate than deep-rooted perennial vegetation such as shrubs, trees, and perennial grasses.

A lysimeter study in Sacramento County at the Kiefer Landfill measured recharge rates within a proposed soil cover (sandy clay loam soils) that was vegetated with annual grasses similar to the vegetation at the Site. During the 2002 through 2005 water years, the average annual recharge rates were measured to be 3.0 inches during a period in which annual precipitation averaged 13.99 inches, compared with a long-term average annual precipitation of 17.62 inches (CH2M HILL, 2007). This small sloped lysimeter site likely also would have generated somewhat more runoff and less infiltration and hence recharge of precipitation than the fairly flat and larger Frontier Fertilizer Site. Consequently, **the annual recharge rates to groundwater in an average year at the Site are estimated to be at least 3.0 inches per year under current conditions.** This is the recharge rate that the deficit irrigation strategy would need to operate within.

8.0 Onsite Irrigation Reuse Alternatives

Two possible onsite irrigation reuse alternatives were developed for consideration. The primary difference between the alternatives is the amount of irrigation and consequently the amount of recharge back to the groundwater system. The two alternatives are briefly described as follows:

1. **Deficit Irrigated Mixed Landscape Vegetation:** Under this alternative, a mixed stand of deep-rooted vegetation would be established, and irrigation water would be applied at deficit irrigation rates. The system would be designed to operate without increasing recharge to groundwater within the influence of the groundwater capture zone over and above existing recharge rates.
2. **Fully Irrigated Poplar Tree Stand:** Under this alternative, a dense stand of poplar trees would be established, and water would be applied up to agronomic rates for hydraulic or nitrogen loading, whichever is most limiting. When fully irrigated, this system would use substantially more water than the first alternative but would increase the recharge to groundwater at the Site over and above the existing recharge rates.

The potential crop water use, leaching necessary to manage soil salinity, and projected irrigation water budgets for both alternatives are described in the following sections.

8.1 Potential Crop Water Use

The potential crop water use (consumptive use) is determined by combining appropriate crop coefficients with reference evapotranspiration rates. These are a function of vegetation and climatic conditions.

Crop Coefficients—Deficit Irrigated Mixed Landscape Vegetation

The vegetation goals for this scenario would be to establish a mixed stand of trees, shrubs, and grasses that can root deeply within Site soils and be fairly drought and salt tolerant. Although further study into a proposed vegetation palate and landscaping plan would be advised if this project is pursued further, a preliminary list of species was developed (Table 5) in order to provide an estimate of potential landscape water use.

TABLE 5
Plant Water Use and Salinity Thresholds for Representative Landscape Species
Plan for Implementing Options for Reuse of Frontier Fertilizer Treated Groundwater, Frontier Fertilizer Superfund Site, Davis, California

	Water Use Rating			Salinity Tolerance
Plant Species	**High**	**Moderate**	**Low**	**Salt Spray/Soil Salinity**
Trees				
Cupressus sempervirens L. (Italian cypress)		X		M/M
Quercus virginiana (live oak)		X		H/T
Populus deltoides x nigra (DN hybrid poplar)	X			M/T
Shrubs				
Ceanothus spp.			X	T/M
Lantana camara L. (lantana)			X	H/T
Nerium oleander (oleander)			X	H/T
Turfgrass				
Lolium perenne. L. (perennial ryegrass)	X			M/M
Festuca arundinacea Schreb. (tall fescue)	X			T/M
Cynodon dactylon (L.) Pers. (bermuda grass)		X		T/T

Note: Salinity tolerance values are from Wu and Dodge (2005). Water use ratings are from UCCE/DWR (2000). Definitions of soil salinity tolerance are as follows:

highly tolerant (H): acceptable soil ECe greater than 6 dS m^{-1}
tolerant (T): acceptable soil ECe greater than 4 and less than 6 dS m^{-1}
moderately tolerant (M): acceptable soil ECe greater than 2 and less than 4 dS m^{-1}
sensitive (low tolerance) (S): acceptable soil EC less than 2 dS m^{-1}

Landscape coefficients (KL) are used in conjunction with ETo (reference grass evapotranspiration) to estimate landscape-specific evapotranspiration rates (ET_L). For mixed landscapes, the relationship between water use at the landscape level and landscape coefficient is as follows:

$$ET_L = K_L \times ETo$$

The landscape coefficient is similar to the crop coefficient, but its value is based on plant species and density, plus a microclimate factor, as shown below:

$$K_L = k_s \times k_d \times k_{mc}$$

Ranges of landscape coefficients are provided in Table 6.

TABLE 6
Range of Values for Landscape Coefficient Factors
Plan for Implementing Options for Reuse of Frontier Fertilizer Treated Groundwater, Frontier Fertilizer Superfund Site, Davis, California

Water Use Rating	Species (k_s)	Density (k_d)	Microclimate (k_{mc})
Very low	< 0.1	--	--
Low	0.1-0.3	0.5-0.9	0.5-0.9
Moderate	0.4-0.6	1.0	1.0
High	0.7-0.9	1.1-1.3	1.1-1.4

Note: Water use ratings are from UCCE/DWR (2000).

The species factor considers whether plant species have high versus low water consumption. If landscape plants have variable water use requirements, k_s will represent the value associated with the species having the highest water demand. The density factor considers leaf area/cover, with higher k_D values for mature, multi-tiered plantings having high densities and lower k_D values used for newly planted areas having lower densities. The microclimate factor considers whether the landscape is shaded or protected from wind (low value), or in an exposed environment with reflective surfaces (for example, a parking lot) (higher value). The ET calculation in this general, landscape approach is uncertain, because there is a range of potential values that could be assigned for each variable used to determine K_L. According to Tanji et al., while this method takes into account factors that affect the K_L, quantitative data are not readily available, and thus $ET_o \times K_L$ produces a rough initial estimate of ET.

For this application, moderate species and microclimate factors and a high density factor have been assumed. Using the mid-range values for these factors produces a K_L of 0.60.

Crop Coefficients—Fully Irrigated Poplar Tree Stand

The vegetation goal for this scenario would be to establish a dense stand of poplar trees, which are a relatively high water use crop with relatively low maintenance requirements. Typical tree spacings would be 6 by 12 feet with an approximate 600-tree-per-acre planting density. Crop coefficients for different age class poplar tree stands were developed by Gochis and Cuenca (2000) in Eastern Oregon (Table 7). These values show that first year water use is 63 percent of the water use for a mature stand (4 years and older). Once the stand canopy is closed at around the 4th year, water use thereafter is fairly consistent.

TABLE 7
Poplar Tree Crop Coefficients (relative to ET_0)
Plan for Implementing Options for Reuse of Frontier Fertilizer Treated Groundwater, Frontier Fertilizer Superfund Site, Davis, California

Month	First Year	Second Year	Third Year	Fourth Year and Older
January	0.35	0.35	0.35	0.35
February	0.35	0.35	0.35	0.35
March	0.35	0.35	0.35	0.35
April	0.35	0.39	0.48	0.41
May	0.37	0.47	0.60	0.66
June	0.42	0.57	0.73	0.89
July	0.46	0.68	0.87	1.04
August	0.51	0.76	0.96	1.07
September	0.51	0.77	0.95	1.02
October	0.45	0.72	0.71	0.79
November	0.35	0.35	0.35	0.35
December	0.35	0.35	0.35	0.35

Climate Conditions and Potential Crop Water Use

Climate data from the nearest California Irrigation Management Information Station (CIMIS #6, Davis, California) were compiled to estimate average monthly precipitation and ET_o over the last 10 years (Table 8). Using the appropriate K_L and K_C factors, average landscape and poplar tree ET rates were also estimated.

TABLE 8
10-year Average Monthly Precipitation, ET_o and Estimated Crop ET for the Davis Area
Plan for Implementing Options for Reuse of Frontier Fertilizer Treated Groundwater, Frontier Fertilizer Superfund Site, Davis, California

Month	Precipitation (in)	ET_o (in)	ET-landscape (in)	ET-poplar trees* (in)
January	3.08	1.18	0.71	0.41
February	4.26	1.85	1.11	0.65
March	1.78	3.8	2.28	1.33
April	1.31	5.15	3.09	2.11
May	0.51	7.06	4.24	4.66
June	0.13	8.21	4.93	7.31
July	0.07	8.35	5.01	8.68

TABLE 8
10-year Average Monthly Precipitation, ET_o and Estimated Crop ET for the Davis Area
Plan for Implementing Options for Reuse of Frontier Fertilizer Treated Groundwater, Frontier Fertilizer Superfund Site, Davis, California

Month	Precipitation (in)	ET_o (in)	ET-landscape (in)	ET-poplar trees* (in)
August	0.06	7.43	4.46	7.95
September	0.07	5.82	3.49	5.94
October	0.7	4.18	2.51	3.30
November	1.8	1.85	1.11	0.65
December	3.61	1.24	0.74	0.43
TOTAL	**17.37**	**56.11**	**33.67**	**43.42**

* Poplar tree water use is reported for trees 4 years and older.

The estimated water use for the landscape scenario is around 34 inches with water use for a mature poplar tree stand around 43 inches.

8.2 Leaching Requirements

Plants generally exclude salts when taking up water; thus, as soil water is used by plants or evaporates from the soil surface, salts are accumulated in the root zone, increasing the salinity levels and potential impacts to vegetation. If necessary, salinity can be managed with an irrigation leaching fraction to periodically or continuously flush accumulated salts below the soil depth occupied by most plant roots. Calculation of the leaching fraction uses the following equation (Ayers and Westcot, 1989):

$$LF = \frac{EC_w}{5(EC_{et}) - EC_w}$$

where LF = leaching fraction
EC_w = EC of irrigation water (dS/m)
EC_{et} = Plant threshold EC of soil saturation paste extract (dS/m)

The leaching fraction can then be used to calculate the additional irrigation requirement:

$$LR = \frac{GIWR}{(1-LF)}$$

where LR = Leaching requirement (in)
GIWR = Gross irrigation water requirement
LF = Leaching fraction

Alternatively, for deficit irrigated areas, the GIWR can be replaced with the actual applied irrigation water to assess whether the calculated deep percolation meets the LR.

This procedure was used to calculate the LF for both alternatives, with the LR assessed in the following section where applied water calculations are presented. For the mixed landscape scenario, an EC_{et} of 4 dS/m was assumed, which is the dividing line between moderate and tolerant classifications for soil salinity tolerance (Wu and Dodge, 2005). For poplar trees, Shannon et al. (1999) reported an average EC_{et} of 5.3 dS/m across eight different clones. Using these values, the required LF was calculated as 11 percent for the mixed landscape and 8 percent for the poplar tree irrigation. This is the amount of leaching necessary to maintain the soil salinity balance without detriment to the managed vegetation.

8.3 Irrigation Water Budgets

Irrigation water budgets were completed for both vegetation and irrigation alternatives using the CH2M HILL Root Zone Water Balance Model and assuming average climate conditions. The irrigation water budgets account for incoming precipitation and irrigation, soil water storage, plant evapotranspiration, and deep percolation or recharge to groundwater. This model also incorporates the effects of drought and soil salinity on reducing ET as presented by Allen et al. (1998). Detailed water budget output is presented in Appendix B with a summary provided in Table 9. Both scenarios are based on an irrigated area of 8.5 acres being available at the Site.

TABLE 9
Irrigation Water Budget Summaries
Plan for Implementing Options for Reuse of Frontier Fertilizer Treated Groundwater, Frontier Fertilizer Superfund Site, Davis, California

Parameter	Units	Deficit Irrigated Mixed Landscape	Fully Irrigated Poplar Tree Stand
Annual applied water	MG	4.5	8.6
	inches	20	37
Annual applied nitrogen	lb/ac	132	240
Recharge to groundwater (deep percolation)	inches	3.0	9.3

For the deficit irrigated mixed landscape, a total irrigation application of 20 in/yr (4.5 MG/yr) is projected. This amount of applied water was adjusted until the deep percolation value was no greater than 3 in/yr. With this level of irrigation, the total applied nitrogen is 132 lb N/ac/yr, which is the estimated agronomic nitrogen rate for the mixed landscape trees and shrubs. The LR necessary to maintain the soil salinity balance was 2.2 inches and, hence, was met with the projected deep percolation of 3 inches.

For the poplar tree irrigation scenario, irrigation was adjusted downward from full irrigation water requirements to the amount that would not exceed the agronomic nitrogen rate of 240 lb N/ac/yr for mature trees. Using this limit, a total irrigation application of 37 in/yr (8.6 MG/yr) is projected. This vegetation and irrigation alternative would produce an estimated 9.3 inches of recharge to groundwater each year during the months of December through March. This would result in about 4.5 acre-feet (1.5 MG) of additional recharge to groundwater within the capture zone each year. The LR necessary to maintain the soil salinity balance for this scenario was 3.0 inches and, hence, was met with the projected deep percolation of 9.3 inches.

For both of the above irrigation scenarios, a mixture of microspray and bubbler or drip irrigation was assumed. Because of the very low leaching fractions targeted for these operations, these are the only irrigation methods capable of obtaining the high level of irrigation uniformity required. Flood irrigation is also suitable because the Site is relatively level, and this form of irrigation can be implemented at a lower capital cost and requires less O&M.

In Figure 2, the total monthly volumes of irrigation for the two scenarios are compared against the treated water (TW) production rates. For all months of the year, there is additional TW available for irrigation, suggesting that a greater area could be irrigated under the same management strategy, thereby increasing the amount of irrigated reuse.

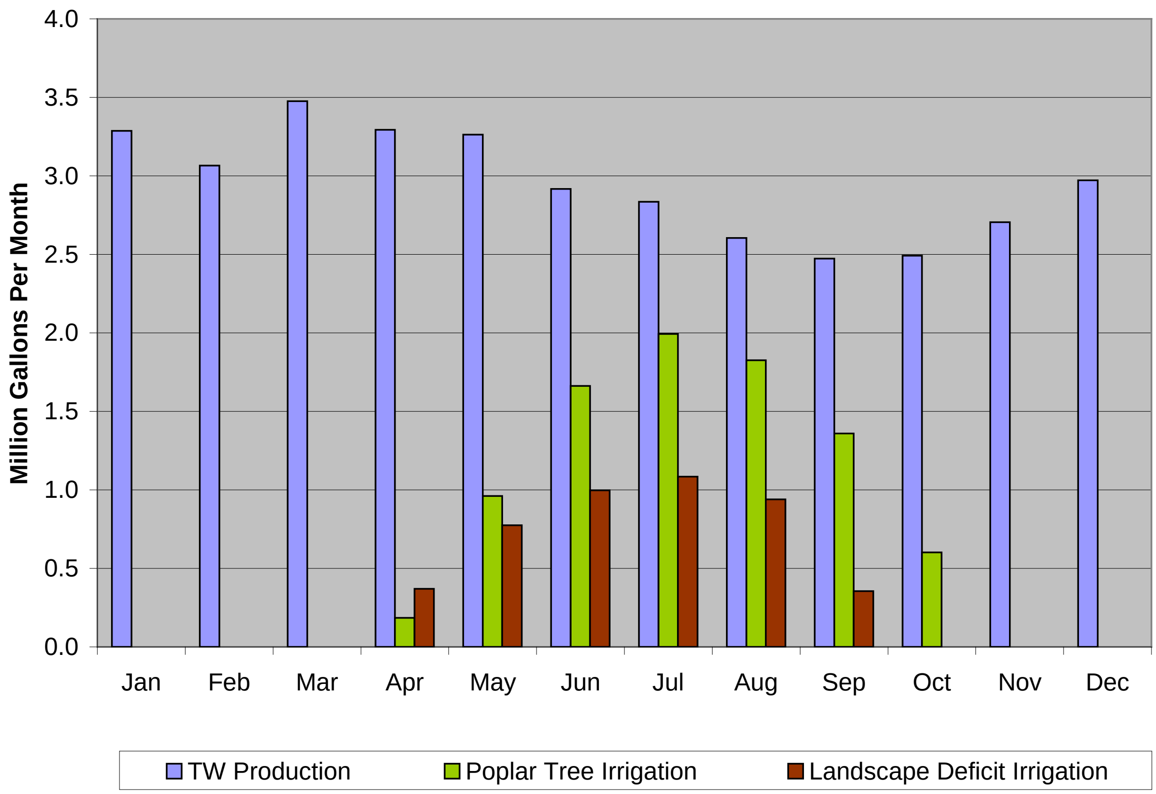

FIGURE 2
Treated Water Production and Use Estimates

9.0 Cost Savings Evaluation

The projected cost savings through avoided sewer charges were assessed for both alternatives and are presented in Appendix C. Using the projected industrial sewer rates from Foresight Consulting (2007), sewer charges over the next 10 years are projected at about $3 million with a present worth cost of $2.2 million (5 percent discount rate) if no reuse is implemented. For the fully irrigated poplar tree stand reuse alternative, the present worth cost savings is projected at $535,000 over the 10-year period. With the deficit irrigated mixed landscape reuse alternative, this present worth cost savings is reduced to about $280,000.

Implementation of either of the onsite irrigation alternatives will incur costs that must be evaluated against the potential cost savings. A list of probable cost items is provided below.

Capital Costs

- Facilities design
- Permit applications
- Removal of foundations and regrading
- Plowing and discing
- Irrigation application system
- Irrigation pump
- Additional operational storage
- Planting of Site vegetation

Ongoing Operations and Maintenance Costs

- O&M of irrigation system
- O&M of vegetation
- Additional monitoring
- Annual reporting

Before budgetary cost estimates are prepared for the onsite reuse alternatives, additional discussion is necessary to establish Site objectives and constraints and to agree upon implementation and operations strategies.

10.0 Conclusions

Several reuse options have been identified and evaluated. The options that warrant further study include (in the approximate order of feasibility):

- Irrigation of Onsite Landscaping
- Distribution of Water for Dust Control
- Irrigation of Highway Landscaping
- Irrigation of Nearby Agricultural Fields
- Irrigation of City of Davis Parks and Greenbelts or private property landscaping.

An assessment of reclaimed water suitability for irrigation uses concluded that the primary limitations were the moderate salinity and elevated nitrate concentrations in the treated groundwater. This assessment also concluded that the water is generally suitable for landscape irrigation as long as appropriate measures are taken to exclude particularly salt-sensitive species, maintain appropriate leaching fractions, and prevent overspray of water onto foliage, where plant appearance is important.

One of the primary limitations for reuse of the recycled water onsite is the potential impact to the contaminated groundwater collection effectiveness. Before an onsite irrigation alternative is finalized, an assessment of the contaminated groundwater collection effectiveness under current conditions and the ultimate operational objectives for the Site should be reviewed to determine whether any additional onsite recharge would be acceptable.

With the 8.5 acres of land available for landscaping at the Site, irrigation demands ranged from 4.5 to 8.6 MG/yr, compared with the 35 MG/yr of reclaimed water produced. Irrigation water demand varies seasonally, and peak demand occurs in July. For each landscaping scenario, there is a period of about 5 months (November through March) during which no irrigation would be applied. The limitations on the amount of irrigation water that can be applied are driven by resulting recharge to groundwater for one scenario and agronomic loading of nitrogen for the other scenario.

Cost estimates for discharge to the sanitary sewer over the next 10 years are projected at about $3 million. Projected present worth cost savings in avoided sewer charges range from $280,000 to $535,000 over the next 10 years for the two onsite irrigation alternatives. In order to evaluate the cost-benefit of these reuse options, budgetary cost estimates are needed for the capital and O&M expenses required to implement these options.

Landscape irrigation appears to be a viable alternative, alone or in combination with other alternatives, for reuse of treated groundwater at the Site. Several ancillary benefits aside from the potential cost savings include the enhanced Site aesthetics and reduced impact on the City of Davis potable water resources and sewerage system. This alternative should be detailed further to establish the implementation approaches and to develop budgetary cost estimates.

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Appendix A
General Guidelines for Irrigation Water Quality

APPENDIX A

General Guidelines for Irrigation Water Quality

FAO 29 REV. 1 – TABLE 1
Guidelines for Interpretations of Water Quality for Irrigation[a]

Potential Irrigation Problem	Units	Degree of Restriction on Use: None	Slight to Moderate	Severe
Salinity (affects crop water availability)[b]				
EC_w	dS/m	< 0.7	0.7–3.0	> 3.0
TDS	mg/L	< 450	450–2,000	> 2,000
Infiltration (affects infiltration rate of water into the soil. Evaluate using EC_w and SAR together)[c]				
SAR = 0–3	and EC_w =	> 0.7	0.7–0.2	<0.2
= 3–6	=	>1.2	1.2–0.3	<0.3
= 6–12	=	>1.9	1.9–0.5	<0.5
= 12–20	=	>2.9	2.9–1.3	<1.3
= 20–40	=	>5.0	5.0–2.9	<2.9
Specific Ion Toxicity (affects sensitive crops)				
Sodium (Na)[d]				
Surface Irrigation	SAR	< 3	3–9	>9
Sprinkler Irrigation	meq/L	< 3	> 3	
Chloride (Cl)[d]				
Surface Irrigation	[meq/L]	< 4	4–10	> 10
Sprinkler Irrigation	[meq/L]	< 3	> 3	
Boron (B)[e]	[mg/L]	< 0.7	0.7–3.0	> 3.0
Miscellaneous Effects (affects susceptible crops)				
Nitrogen (NO_3-N)[f]	mg/L	< 5	5–30	> 30
Bicarbonate (HCO_3)— overhead sprinkling only	meq/L	< 1.5	1.5–8.5	> 8.5
pH			Normal Range 6.5–8.4	

Notes:

[a] Adapted from the University of California Committee of Consultants (1974).

[b] EC_w means electrical conductivity, a measure of the water salinity, reported in deciSiemens per meter (dS/m) at 25 degrees Celsius or in units of millimhos per centimeter (mmho/cm). Both are equivalent. TDS means total dissolved solids, reported in milligrams per liter (mg/L).

[c] SAR means sodium adsorption ratio. SAR is sometimes reported by the symbol RNa. At a given SAR, the infiltration rate increases as water salinity increases.

[d] For surface irrigation, most tree crops and woody plants are sensitive to sodium and chloride: use the values shown. Most annual crops are not sensitive: use the salinity tolerance data in "Ref-Crop Salt Tolerance." With overhead sprinkler irrigation and low humidity (<30%), sodium and chloride may be absorbed through the leaves of sensitive crops. For crop sensitivity to absorption and chloride tolerance of selected fruit crops, see FAO 29 Rev. 1.

[e] For boron tolerances, see FAO 29 Rev. 1.

[f] NO_3-N means nitrate nitrogen reported in terms of elemental nitrogen (NH_4-N and Organic-N should be included when wastewater is being tested.)

Appendix B
Irrigation Water Budgets

Root Zone Irrigation Water Balance - Poplar Trees

Project Name: Frontier Fertilizer
Project Number: 384792

Designer: Rose/Smesrud
Crop: Poplar Trees

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
	Days/Month	31	28	31	30	31	30	31	31	30	31	30	31	365
Water Supply														
Average Precipitation	[in]	3.08	4.26	1.78	1.31	0.51	0.13	0.07	0.06	0.07	0.70	1.80	3.61	17.37
% Effective Precipitation	[%]	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	
Surface Runoff	[in]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Effective Rainfall	[in]	3.08	4.26	1.78	1.31	0.51	0.13	0.07	0.06	0.07	0.70	1.80	3.61	17.37
Available Water	[in]	14.24	13.28	15.06	14.27	14.14	12.64	12.28	11.28	10.71	10.80	11.72	12.87	153.30
	[MG]	3.3	3.1	3.5	3.3	3.3	2.9	2.8	2.6	2.5	2.5	2.7	3.0	35.4
	[mgd]	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	
	[ac-ft]	10.1	9.4	10.7	10.1	10.0	9.0	8.7	8.0	7.6	7.6	8.3	9.1	108.6
Available Water Flow to Irrigation/Storage?	(Y/N)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	
Irrigation Requirements and Management														
Potential Crop Evapotranspiration	[in]	0.41	0.65	1.33	2.11	4.66	7.31	8.68	7.95	5.94	3.30	0.65	0.43	43.42
Actual Crop Evapotranspiration	[in]	0.41	0.65	1.33	2.11	4.66	7.31	8.68	7.95	5.93	3.26	0.65	0.43	43.37
Net Irrigation Requirement	[in]	0.00	0.00	0.00	0.80	4.15	7.18	8.61	7.89	5.87	2.60	0.00	0.00	37.11
Gross Irrigation Requirement	[in]	0.00	0.00	0.00	0.84	4.37	7.56	9.07	8.30	6.18	2.74	0.00	0.00	39.07
	[MG]	0.0	0.0	0.0	0.2	1.0	1.7	2.1	1.9	1.4	0.6	0.0	0.0	9.0
	[ac-ft]	0.0	0.0	0.0	0.6	3.1	5.4	6.4	5.9	4.4	1.9	0.0	0.0	27.7
Total Irrigation Applied	[in]	0.00	0.00	0.00	0.80	4.16	7.20	8.63	7.91	5.89	2.61	0.00	0.00	37.20
	[MG]	0.0	0.0	0.0	0.2	1.0	1.7	2.0	1.8	1.4	0.6	0.0	0.0	8.6
	[ac-ft]	0.0	0.0	0.0	0.6	2.9	5.1	6.1	5.6	4.2	1.8	0.0	0.0	26.4
Irrigation Losses	[in]	0.00	0.00	0.00	0.04	0.21	0.36	0.43	0.40	0.29	0.13	0.00	0.00	1.86
Soil Profile Water Balance														
Beginning Soil Moisture	[in]	17.8	17.8	17.8	17.8	17.8	17.6	17.2	16.8	16.5	16.2	16.1	17.3	
Ending Soil Moisture	[in]	17.8	17.8	17.8	17.8	17.6	17.2	16.8	16.5	16.2	16.1	17.3	17.8	
Deep Percolation	[in]	2.7	3.6	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.6	9.3
Soil Profile Salt Balance														
Beginning Soil Salinity, ECe	[dS/m]	2.5	1.8	1.2	1.1	1.1	1.4	1.8	2.3	2.7	3.0	3.2	3.2	
Ending Soil Salinity, ECe	[dS/m]	1.8	1.2	1.1	1.1	1.4	1.8	2.3	2.7	3.0	3.2	3.2	2.5	

Irrigated Land = 8.5 acres

Soil Water Storage at Field Capacity = 17.82 inches
Soil Water Storage at Permanent Wilting Point = 5.94 inches
Available Water Holding Capacity = 11.88 inches
Soil Water Storage at Minimum Management Allowed Soil Moisture = 11.88 inches

General Design Parameters

Crop Parameters

Depletion Fraction	[-]	0.50
Rooting Depth	[ft]	5.0
Yield Response Factor	[-]	1.00
Salinity Induced Yield Reduction	[%/(dS/m)]	12.0
Threshold ECe	[dS/m]	5.0

Notes:

Depletion Fraction - Average fraction of total available soil water that can be depleted from the root zone before moisture stress resulting in ET reduction occurs. Yield Response Factor - A slope factor describing the reduction in relative yield according to the reduction in ETc caused by soil water shortage. Salinity Induced Yield Reduction - A slope factor describing the reduction in relative yield according to an incremental increase in ECe for values above the threshold ECe. Threshold ECe - Electrical conductivity of the saturation extract at the threshold of ECe when crop yield first reduces below the maximum yield potential.

Soil Parameters

Field Capacity	[in/in]	0.30
Permanent Wilting Point	[in/in]	0.10

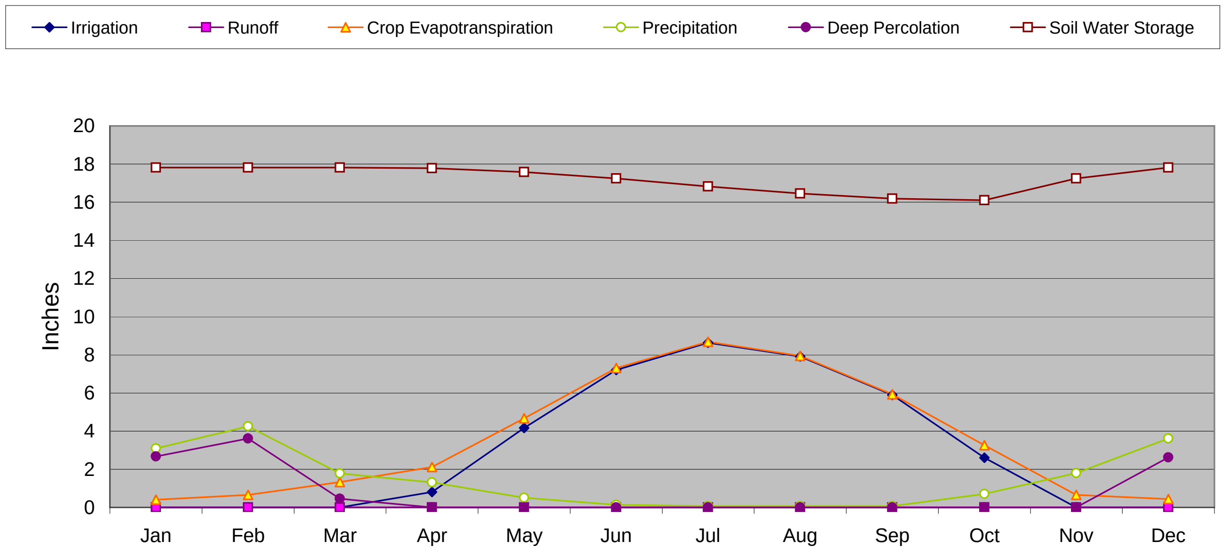
Field Capacity - Defined as the water held at a tension of 0.33 Bar. Permanent Wilting Point - Defined as the water held at a tension of 15 Bar. All water content measurements expressed in inches of water per inch of rooting depth.

Irrigation System Parameters

Combined Irrigation Application Efficiency	[-]	0.95

Combined Irrigation Application Efficiency - (average depth of water infiltrated and retained in the root zone following irrigation) / (average depth of water applied).

ROOT ZONE WATER BALANCE CHART



Root Zone Irrigation Water Balance - Deficit Irrigated Mixed Landscape

Project Name: Frontier Fertilizer
Project Number: 384792

Designer: Smesrud
Crop: Mixed Landscape

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
	Days/Month	31	28	31	30	31	30	31	31	30	31	30	31	365
Water Supply														
Average Precipitation	[in]	3.08	4.26	1.78	1.31	0.51	0.13	0.07	0.06	0.07	0.70	1.80	3.61	17.37
% Effective Precipitation	[%]	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	
Surface Runoff	[in]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Effective Rainfall	[in]	3.08	4.26	1.78	1.31	0.51	0.13	0.07	0.06	0.07	0.70	1.80	3.61	17.37
Available Water	[in]	14.24	13.28	15.06	14.27	14.14	12.64	12.28	11.28	10.71	10.80	11.72	12.87	153.30
	[MG]	3.3	3.1	3.5	3.3	3.3	2.9	2.8	2.6	2.5	2.5	2.7	3.0	35.4
	[mgd]	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	
	[ac-ft]	10.1	9.4	10.7	10.1	10.0	9.0	8.7	8.0	7.6	7.6	8.3	9.1	108.6
Available Water Flow to Irrigation/Storage?	(Y/N)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	
Irrigation Requirements and Management														
Potential Crop Evapotranspiration	[in]	0.71	1.11	2.28	3.09	4.24	4.93	5.01	4.46	3.49	2.51	1.11	0.74	33.68
Actual Crop Evapotranspiration	[in]	0.69	1.11	2.28	3.09	4.24	4.93	4.96	4.30	3.31	2.36	1.02	0.68	32.96
Net Irrigation Requirement	[in]	0.00	0.00	0.50	1.78	3.73	4.80	4.94	4.40	3.42	1.81	0.00	0.00	25.40
Gross Irrigation Requirement	[in]	0.00	0.00	0.53	1.88	3.93	5.06	5.20	4.63	3.60	1.91	0.00	0.00	26.73
	[MG]	0.0	0.0	0.1	0.4	0.9	1.2	1.2	1.1	0.8	0.4	0.0	0.0	6.2
	[ac-ft]	0.0	0.0	0.4	1.3	2.8	3.6	3.7	3.3	2.6	1.3	0.0	0.0	18.9
Total Irrigation Applied	[in]	0.00	0.00	0.00	1.60	3.36	4.32	4.70	4.07	1.54	0.00	0.00	0.00	19.59
	[MG]	0.0	0.0	0.0	0.4	0.8	1.0	1.1	0.9	0.4	0.0	0.0	0.0	4.5
	[ac-ft]	0.0	0.0	0.0	1.1	2.4	3.1	3.3	2.9	1.1	0.0	0.0	0.0	13.9
Irrigation Losses	[in]	0.00	0.00	0.00	0.08	0.17	0.22	0.23	0.20	0.08	0.00	0.00	0.00	0.98
Soil Profile Water Balance														
Beginning Soil Moisture	[in]	15.3	17.7	17.8	17.3	17.1	16.5	15.8	15.4	15.0	13.2	11.6	12.4	
Ending Soil Moisture	[in]	17.7	17.8	17.3	17.1	16.5	15.8	15.4	15.0	13.2	11.6	12.4	15.3	
Deep Percolation	[in]	0.0	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0
Soil Profile Salt Balance														
Beginning Soil Salinity, ECe	[dS/m]	3.2	3.2	2.1	2.1	2.1	2.3	2.6	2.8	3.1	3.2	3.2	3.2	
Ending Soil Salinity, ECe	[dS/m]	3.2	2.1	2.1	2.1	2.3	2.6	2.8	3.1	3.2	3.2	3.2	3.2	

Irrigated Land = 8.5 acres

Soil Water Storage at Field Capacity = 17.82 inches
Soil Water Storage at Permanent Wilting Point = 5.94 inches
Available Water Holding Capacity = 11.88 inches
Soil Water Storage at Minimum Management Allowed Soil Moisture = 11.88 inches

General Design Parameters

Crop Parameters		
Depletion Fraction	[-]	0.50
Rooting Depth	[ft]	5.0
Yield Response Factor	[-]	1.00
Salinity Induced Yield Reduction	[%/(dS/m)]	8.0
Threshold ECe	[dS/m]	3.5

Notes:

Depletion Fraction - Average fraction of total available soil water that can be depleted from the root zone before moisture stress resulting in ET reduction occurs. Yield Response Factor - A slope factor describing the reduction in relative yield according to the reduction in ETc caused by soil water shortage. Salinity Induced Yield Reduction - A slope factor describing the reduction in relative yield according to an incremental increase in ECe for values above the threshold ECe. Threshold ECe - Electrical conductivity of the saturation extract at the threshold of ECe when crop yield first reduces below the maximum yield potential.

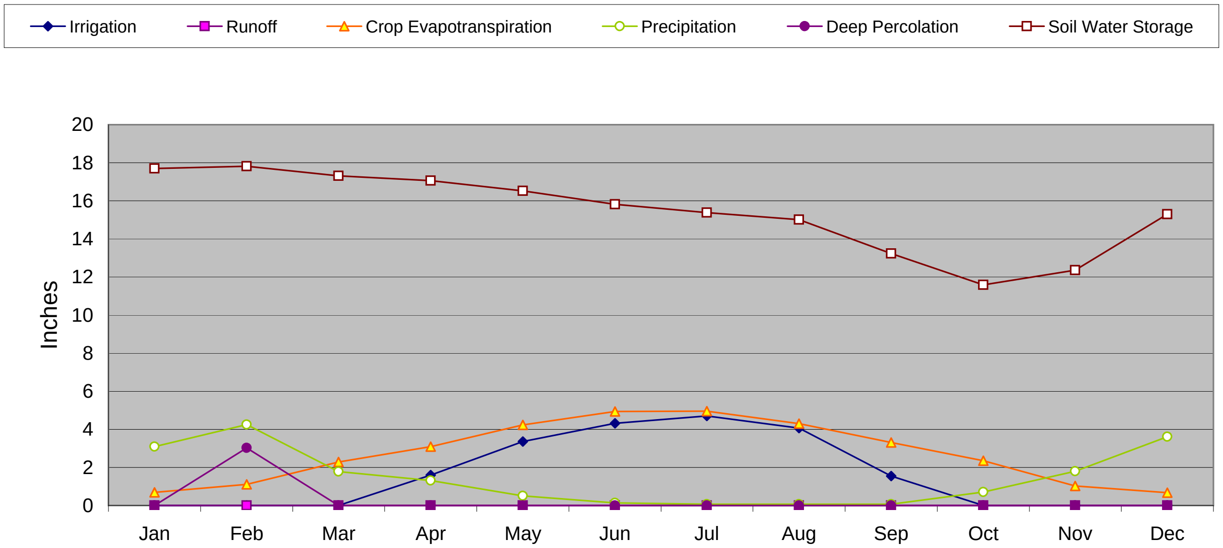
Soil Parameters		
Field Capacity	[in/in]	0.30
Permanent Wilting Point	[in/in]	0.10

Field Capacity - Defined as the water held at a tension of 0.33 Bar. Permanent Wilting Point - Defined as the water held at a tension of 15 Bar. All water content measurements expressed in inches of water per inch of rooting depth.

Irrigation System Parameters		
Combined Irrigation Application Efficiency	[-]	0.95

Combined Irrigation Application Efficiency - (average depth of water infiltrated and retained in the root zone following irrigation) / (average depth of water applied).

ROOT ZONE WATER BALANCE CHART



Appendix C
Cost Savings Table

Frontier Fertilizer Treated Groundwater Reuse Cost Savings

Option A - Continue Discharge of All Treated Water to Sewer

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Annual RW Production (MG)	35.383	35.383	35.383	35.383	35.383	35.383	35.383	35.383	35.383	35.383	35.383
Annual Sewer Volume (MG)	35.383	35.383	35.383	35.383	35.383	35.383	35.383	35.383	35.383	35.383	35.383
Sewer Rate ($/ccf)	$3.9466	$4.1834	$4.5181	$5.0150	$5.7171	$6.3460	$6.4730	$6.6024	$6.7344	$6.8691	$7.0065
Annual Sewer Charges	$186,688	$197,889	$213,722	$237,227	$270,439	$300,188	$306,195	$312,316	$318,563	$324,934	$331,433

Annual Discount Rate	*5%*
Total Present Worth Cost - 10 years	*$2,201,000*

Option B - Develop a Fully Irrigated Poplar Tree Stand Over 8.5 acres

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Annual RW Production (MG)	35.383	35.383	35.383	35.383	35.383	35.383	35.383	35.383	35.383	35.383	35.383
Annual RW Irrigation (MG)	8.6	8.6	8.6	8.6	8.6	8.6	8.6	8.6	8.6	8.6	8.6
Annual Sewer Volume (MG)	26.783	26.783	26.783	26.783	26.783	26.783	26.783	26.783	26.783	26.783	26.783
Sewer Rate ($/ccf)	$3.9466	$4.1834	$4.5181	$5.0150	$5.7171	$6.3460	$6.4730	$6.6024	$6.7344	$6.8691	$7.0065
Savings in Sewer Charges	$45,375	$48,098	$51,946	$57,659	$65,731	$72,962	$74,422	$75,910	$77,428	$78,977	$80,556
Annual Sewer Charges	$141,313	$149,791	$161,776	$179,568	$204,707	$227,226	$231,773	$236,407	$241,135	$245,957	$250,876

Annual Discount Rate	*5%*
Total Present Worth Cost - 10 years	*$1,666,000*
Present Worth Savings - 10 years	*$535,000*

Option C - Develop Deficit Irrigated Mixed Landscape Over 8.5 acres

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Annual RW Production (MG)	35.383	35.383	35.383	35.383	35.383	35.383	35.383	35.383	35.383	35.383	35.383
Annual RW Irrigation (MG)	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
Annual Sewer Volume (MG)	30.883	30.883	30.883	30.883	30.883	30.883	30.883	30.883	30.883	30.883	30.883
Sewer Rate ($/ccf)	$3.9466	$4.1834	$4.5181	$5.0150	$5.7171	$6.3460	$6.4730	$6.6024	$6.7344	$6.8691	$7.0065
Savings in Sewer Charges	$23,743	$25,168	$27,181	$30,170	$34,394	$38,178	$38,942	$39,720	$40,515	$41,325	$42,152
Annual Sewer Charges	$162,945	$172,722	$186,541	$207,056	$236,044	$262,010	$267,254	$272,596	$278,048	$283,609	$289,281

Annual Discount Rate	*5%*
Total Present Worth Cost - 10 years	*$1,921,000*
Present Worth Savings - 10 years	*$280,000*

Notes:
Sewer rates through 2016 were taken from Foresight Consulting (2007). Rates in subsequent years were increased by an estimated 2% per year.