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# Evaluation of Selenium Remediation Concepts for Selected Tributaries/Drains in the Grand Valley of Western Colorado

Performed in conjunction with the Grand Valley Selenium Task Force through the Bureau of Reclamation's Technical Assistance to States Program

U.S. Department of the Interior
Bureau of Reclamation

March 2006

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# Executive Summary

The purpose of this appraisal (pre-feasibility) study was to determine if reasonable and implementable remediation measures exist to reduce selenium concentrations and meet state water-quality standards for selenium in tributaries/drains on the north side of the Colorado River in the Grand Valley.

The area covered by this study is the irrigated zone of agricultural, residential and commercial development in the Grand Valley bounded on the south by the Colorado River and on the north by the Government Highline Canal. The study evaluates remediation for 12 tributaries/drains within the study area that currently violate Colorado's selenium standard of 4.6 ppb. Other stream segments may violate the state's water-quality standards in the Grand Valley, but a complete list has yet to be assembled.

Five alternatives were developed which could possibly meet the standard in these 12 tributaries/drains:

1. Source control with dilution
2. Diversion
3. Permeable reactive barriers
4. Biological treatment with source control and dilution
5. Collection and biological treatment

Evaluations of these alternatives indicate water quality standards for selenium in the Grand Valley tributaries/drains could be met; however, the costs of remediation would be very high, well beyond the capabilities of local entities to fund. Implementation costs range from $73 million up to more than $2 billion. The least expensive project would also have extensive impacts to existing fish and wildlife habitat.

It is suggested that decision-makers weigh reasonableness, spending priorities, value of the existing habitat, and the benefits of such remedial action. It seems that the benefits of any of these remediation alternatives must be much better defined and the significance understood before decisions are made to proceed with further studies of any of these concepts. It is recommended that the Grand Valley Selenium Task Force prepare documentation of the potential benefits of actions to reduce selenium concentrations in these tributaries/drains and compare them with the costs and impacts of alternatives presented in this report. There may be opportunities to accrue similar benefits in higher priority locations at a much lower cost.

## Introduction and Study Purpose

The purpose of this study was to determine if reasonable and implementable remediation measures exist to reduce selenium concentrations and meet state water-quality standards for selenium in tributaries/drains on the north side of the Colorado River in the Grand Valley. The study evaluates remediation for 12 tributaries/drains within the study area (Figure 1) that currently violate Colorado's selenium standard of 4.6 ppb and have temporary modifications, or variances of the state standard. There may be other segments that violate the state's water-quality standards in the Grand Valley; however, a complete list has yet to be assembled.

Please note that the subject watercourses are referred to as "tributaries/drains" in this report. Stakeholders refer to them by various names including washes, arroyos, drains, tributaries, etc. The Bureau of Reclamation designated most of the major watercourses on the north side of the Colorado River as named drains (e.g., Drain D) in the early 20$^{th}$ century because they were identified to carry irrigation return flows back to the Colorado River and are subject to maintenance agreements (legal documents). The Colorado Water Quality Control Division defines a "drain" as a constructed conveyance outside a historical conveyance (i.e. where water never flowed historically). All of the tributaries/drains discussed in this report refer only to the historical watercourses (some of which have been irreversibly altered to serve a drainage function) and not to any constructed (man-made) drains.

Evaluations of potential remedial measures and alternatives were conducted at an appraisal (or pre-feasibility) level of detail to identify concepts worthy of further consideration. The Grand Valley Selenium Task Force will use information developed as part of this study in decisions on whether to promote further remediation studies or to request the Colorado Water Quality Control Commission implement site-specific or ambient water-quality steam standards. It may be appropriate to propose both actions for differing circumstances in an individual tributary/drain. This report documents the study process and results.

## Description of the Study Area and Background

The area covered by this study is the irrigated zone of agricultural, residential and commercial development in the Grand Valley bounded on the south by the Colorado River and on the north by the Government Highline Canal (Figure 1). The study area extends from Palisade to just west of Mack. Irrigated areas south of the river on Orchard Mesa and the Redlands were not considered in this study.

Persigo Wash above the Government Highline Canal

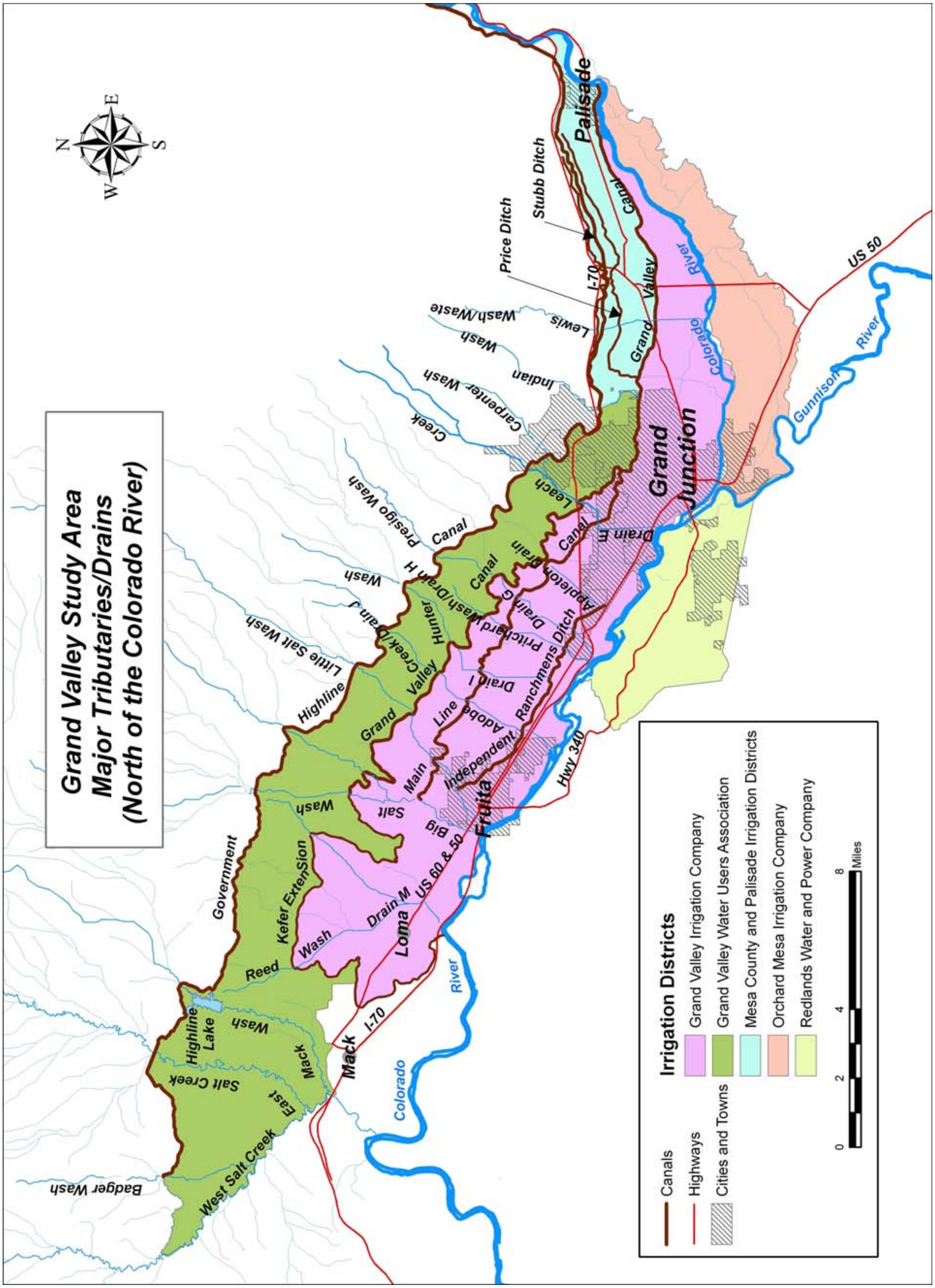

Figure 1 – Study Area

Above the Government Highline Canal, drainages are natural and flow only during and immediately following infrequent precipitation events (e.g., Persigo Wash – see photo, Page 1). Precipitation in the Grand Valley averages about 8 inches a year. Sampling for selenium in natural flows in some of the drainages above the Canal on the west end of the valley showed concentrations of less than 3 ppb during winter runoff events. These segments above the Government Highline Canal are defined as ephemeral streams and are covered by the State's water-quality standards, but are not on the State's 303d list.

Agricultural development began in the Grand Valley in the late 1800's, with the first irrigation systems being constructed in 1883. Presently some 70,000 acres are under irrigation. Within the Grand Valley, irrigation water is removed from the Colorado River by three major diversions -- the Grand Valley Project Diversion Dam at Cameo which feeds the Government Highline Canal and Orchard Mesa Irrigation District, the Grand Valley Irrigation Company Dam at Palisade, and the Redlands Diversion Dam. Irrigation generally occurs in the valley between late March and November 1st. The non-irrigation season runs from November to mid-March.

With the agricultural development of the valley, many of the natural drainages below the Government Highline Canal became conveyances for agricultural irrigation returns and drainage flowing to the Colorado River. These continuous flows in the historical, natural depressions created, in some cases, deep (10 - 20 feet), incised channels. Segments of these natural drainage channels from the Government Highline Canal downstream to their Colorado River confluences are now subject to Colorado's water-quality standard for selenium of 4.6 ppb.

By 1913, high ground-water tables due to tight clay soils were creating damage to the valley's major crops of peaches, apples and pears. Several man-made drains (some of which flow into the natural drainages) were constructed by the Bureau of Reclamation and the Grand Junction Drainage District between 1915 and 1928 within the study area to reduce these high, irrigation-induced, ground-water tables. This practice enabled unusable lands (impacted by ground-water) to be reclaimed for agriculture and other development. The man-made drains are now maintained by the Grand Junction Drainage District and by the Grand Valley Water Users Association (under contract with Reclamation) within their service area. The Drainage District does not maintain natural drainages such as Adobe Creek unless petitioned by the landowner.


Channelized section of Lewis Wash or Lewis Waste east of Grand Junction (31 & D Roads) during irrigation season

Some sections of the natural drainages were channelized in the early to mid 20th century (e.g., Lewis Wash – see photo) as agricultural and urban development occurred in the area. Bureau of Reclamation maps, dated 1945, designated some of the natural drainages as named drains; for example Adobe Creek was designated as "Drain J" within the irrigated area below the Government Highline Canal and Lewis Wash was "Lewis Waste".

Flows in these conveyances presently consist of infrequent storm runoff events but mostly are irrigation return flow (including administrative canal spills and transfers) and ground-water drainage. It is estimated that 95% or more of the flow conveyed by these waterways originates from irrigation sources, the result of man-induced land use changes. Point-source discharges of water and selenium are not a significant source compared to irrigation sources. The sources of ground-water drainage are primarily seepage from the irrigation delivery system (canal, laterals, and ditches) and deep percolation from irrigation applications (on-farm, commercial and residential). Smaller amounts of seepage likely result from unlined ponds and septic systems.

Tributaries/drains on the north side of the Grand Valley are generally considered to have poor water quality, particularly during the non-irrigation season (November – March). This is due primarily to elevated concentrations of dissolved solids and selenium in ground and surface waters. Dissolved solids concentrations in the tributaries are typically too high to allow the water to be used as a stock or irrigation source. Other potentially toxic trace elements have been detected in the tributaries; however, the concentrations detected are less than or close to laboratory reporting limits and do not exceed aquatic life criteria.

These natural and man-made waterways provide many benefits to the Grand Valley and have many uses including:

- conveyance of natural runoff and stormwater,
- conveyance of irrigation return flows and drainage, and
- aquatic and riparian wildlife habitat (an unintended consequence of the irrigation drainage).

Remedial measures have been implemented in the past in the Grand Valley for salinity control. Since the late 1970's, more than $200 million has been spent on lining canals, piping irrigation laterals and installing more efficient on-farm irrigation systems in the study area as part of the ongoing Colorado River salinity control efforts. The US Department of Agriculture's Natural Resources Conservation Service (NRCS; formerly the Soil Conservation Service) and the Department of the Interior's Bureau of Reclamation have been the primary funding entities for these improvements.

Despite these improvements, many unlined irrigation canals and ditches continue to leak. Along with excess deep percolation from irrigation applications, these sources continue to supply the ground-water system where selenium is mobilized. Local ground-water tables rise (analogous to filling a sponge) during the irrigation season. This "sponge" drains and discharges ground-water return flow year-around into the tributaries/drains. The flows reach their highest levels during the irrigation season (March to October), but continue throughout the non-irrigation (November to March) season. Tributaries and drains in irrigated sections of the Grand Valley typically flow throughout the non-irrigation season, reaching low flows (~ 0.1 to 10 cfs) just prior to irrigation resuming again in late March and early April.

Changing land use related to growth in the valley is altering how water is used and patterns of return flow. New small-lot subdivisions are increasing the amount of impervious land area, probably reducing deep percolation from the previous irrigated-agricultural use. Other land uses, such as the rapidly increasing number of small-acreage properties are widely believed to be less efficient with their water than the prior agricultural operators, thus increasing deep percolation and seepage. These aspects are currently under study by the US Geological Survey, Colorado River Basin Salinity Control Forum, Mesa Conservation District and NRCS in the Grand Valley and lower Gunnison River basin.

## Water Quality Standards

The Colorado Water Quality Control Division has classified all surface and subsurface waters which are contained in or flow through the state of Colorado for specific beneficial uses. These specific uses are subject to the adoption of water quality standards for each stream segment Waters that are withdrawn for irrigation use in the delivery system are considered to be waters of the state, but do not have classifications and standards applied.

Alteration of a natural watercourse (e.g., channelization of tributaries) does not affect the designation as "waters of the state," and these waters are still subject to classifications and standards. Man-made drains excavated outside of natural watercourses are not considered to be waters of the state.

The specific water quality standards that apply to streams depend on the use classifications of the segments. Tributaries to the Colorado River in the Grand Valley in Segment 13b (which includes the 12 tributaries/drains evaluated in this report) are use classified as:

- Aquatic Life Warm 2
- Recreation 1a
- Agriculture

The aquatic life use classification is the most stringent in terms of water quality standards that protects aquatic life. The selenium standard associated with the aquatic life use is 4.6 ppb (chronic) and is the most stringent of these uses.

Several tributaries to the Colorado River in the Grand Valley are listed on Colorado's Section 303(d) list of Water Quality Limited Segments Requiring Total Maximum Daily Loads (TMDL). These include tributaries on the north side of the Colorado River from the Government Highline Canal Diversion (Grand Valley Project Diversion Dam) to Salt Creek and the Walker Wildlife Area Ponds. There are likely other tributaries/drains subject to the state standards; but these have not been identified, nor included in the analyses presented in this report.

The Clean Water Act (CWA), as enforced by the USEPA, requires the state of Colorado to develop TMDLs within 13 years from the time of listing of impairment (2002). However, implementation of the TMDL is not a Federal requirement. There is no clear answer to the question of what happens if nothing is done to remediate selenium in these segments. As a result, what may happen in the future if TMDLs are not implemented in the Grand Valley tributaries is unknown. The source of most of the water carried in these tributaries/drains is non-point source irrigation return flow. Discharge of non-point source irrigation return flow is exempt from National Pollutant Discharge Elimination System (NPDES) permitting requirements under the CWA.

## Study Process and Initial Evaluations

The Grand Valley Selenium Task Force decided it was prudent to first investigate whether reasonable and cost-effective measures are available that might allow the selenium standard to be attained in the Grand Valley tributaries/drains. That task is the primary purpose of this study and report. If it was determined the standard could not be attained, future studies might then be undertaken to determine if reasonable and implementable remedial measures exist that could significantly improve conditions for aquatic life in the tributaries/drains.

As an initial step in the study process, the group examined and discussed a general list of possible selenium remediation techniques previously developed by the Gunnison Basin Selenium Task Force and National Irrigation Water Quality Program (NIWQP). Additional potential solutions were then suggested and incorporated to produce a remediation "tool box" and categorization of potential source control, treatment, dilution, and diversion options. The tool box of Categorized Measures is displayed as Table 1.

A general evaluation and screening of various types of actions that might reduce selenium concentrations in the Grand Valley tributaries/drains is presented in Table 2. Actions are presented by major types of reduction measures that could be undertaken. The general impacts of such actions are also displayed.

The next step in the Task Force's process involved formulation of several specific remedial alternatives which are displayed and evaluated in the next section of this report.

# Table 1 - Categorized Remediation Measures

(revised: February 2003)

*Measures previously evaluated by NIWQP/Gunnison Basin Selenium Task Force are designated with an asterisk (*).*

1. **Source control measures**
    a. Irrigation water management including:
        i. Identify soil moisture needs to reduce water application rates
        ii. Educate water users about increasing yield by applying optimal amount of irrigation water to crops*
        iii. Use Hydrogel in agricultural fields *
        iv. Improve water use efficiency on small acreage properties*
    b. Stop irrigation
        i. Land retirement (includes buffer zones with no irrigation)*
        ii. Remove irrigation from residential areas
    c. Control seepage from water conveyance & storage facilities
        i. Line and pipe canals and laterals*
        ii. Use PAM in canals*
        iii. Line ponds (golf course, residential, farm, etc.)*
        iv. Line or pipe tailwater ditches*
    d. Phyto-remediation (growing crops that take selenium from soils)*
    e. Economic incentives to reduce on-farm deep percolation
        i. Increase cost of wasting water to encourage conservation
        ii. Meter irrigation water*
        iii. Legislation to encourage saving or conserving water
        iv. Meter lawn irrigation water and charge appropriately to encourage conservation
    f. Educate water users to provide awareness of problems and solutions (Best Management Practices or BMPs)
    g. Install shallow tile drains to limit deep percolation*
    h. Limit use of septic systems or tie them into centralized wastewater treatment*
    i. Xeriscape suburban residences*
    j. Reduce nitrate fertilizer*

## Table 1 - Categorized Remediation Measures (continued)

2. **Treatment**
    a. Treat the hottest (highest in selenium levels) spots* (using biological or mechanical treatment)
    b. Install tile drains to collect ground water and treat for return to drain*
    c. Wetland treatment cells*
    d. Drain water reuse*
    e. Treat water within the wash (a.k.a. straw bale treatment)*
    f. Use reverse osmosis or ion exchange treatment*
    g. Install reactive permeable barriers*
    h. Plant phreatophytes in no farm zones*

3. **Dilution**
    a. Dilute selenium with canal spills
    b. Purchase water for enhanced flows for aquatic life
    c. Keep Persigo Treatment Plant discharge in Drain G
    d. Cloud seeding (assume this is to increase runoff & total flow)

4. **Diversion**
    a. Intercept ground water with wells and pipe to dilution point in river

5. **Measures not known to reduce selenium concentrations**
    a. Use polyacrylamide (PAM) to seal furrows
    b. Determine if the water quality standard is appropriate to apply to the tributaries
    c. Change water quality selenium standard to ambient or site-specific criteria
    d. Stock more endangered fish
    e. Determine remediation effects to date (from NRCS and Bureau of Reclamation salinity control projects)
    f. Install physical barriers to prevent endangered fish from entering the tributaries/drains
    g. Strengthen the wash to facilitate drainage

6. **Unknown technologies** (additional information is needed)
    a. Geochemical alterations to immobilize selenium
    b. Use fertilizer to neutralize selenium

## Table 2 -- Possible outcomes of various types of selenium reduction actions in Grand Valley tributaries/drains

| Action | How would it be done? | Physical effect in trib/drain & on aquatic habitat | Effect on selenium concentration | What else is needed to meet WQ standard? | Notes / Other considerations |
|---|---|---|---|---|---|
| **Source control by limiting water** available for selenium mobilization | Reduce seepage from irrigation delivery system & ponds. Reduce deep percolation from irrigation of ag fields, lawns, gardens, & landscaping and from septic systems | Reduces <u>volume</u> of ground water return flow, delivery system operational spills, and possibly tailwater & other surface runoff | May increase, decrease, or remain the same | Remaining drain flow with likely high selenium concentration will need to be treated or diluted | Normally the 1st priority before treatment or dilution; target hot spots. Preservation of tailwater & surface runoff could help dilute trib/drain |
| **Source control by removing <u>all</u> water** available for mobilization | All agricultural land would be retired and lawn/garden watering eliminated in the drainage basin; parts of the delivery system would no longer be needed so they could be abandoned | Could become partially dry with the exception of seepage from remaining unlined canals & precipitation events; significantly lower flows likely | If seepage remains, it would likely have likely have higher concentrations due to lack of dilution from spills & tailwater; precipitation events will carry some selenium | Source control or treatment & dilution for any remaining seepage (and for deep perc if only a portion of the basin lands are retired) | Neither USFWS nor EPA considers area-wide land retirement a viable option. It would create widespread economic hardship. This action would also be contrary task force's mission. |
| **Source Control by limiting nitrate** available for mobilization | Limit amounts of nitrate in groundwater which MAY have an impact on mobilization (This is a theory lacking scientific proof at this time.) | None, should not affect water volumes | Unknown, but <u>MAY</u> reduce selenium loading to the drain | More study? Plus, possibly source control, treatment, & dilution | This is an unproven concept with possibly small (5%) reductions; likely hard sell to have landowners reduce fertilizer use |
| **Collection & treatment (biological or mechanical)** | Collect or isolate the most concentrated return flows and treat in a biological or mechanical treatment facility (includes bioreactor concept) | Reduces water volume in some reaches of the trib; reaches where water is removed may be either dewatered or have lower flow | Reduces significantly in some reaches; other reaches may still have high concentrations | Source control measures to minimize volume of water to be treated; dilution may be needed for some reaches | |
| Off-site **treatment** (drain water re-use) | Recycle segregated drain water onto salt tolerant crops, collect drainage to evapotranspire or evaporate | Reduces drain water volume | Remaining water in drain may have similar or lower concentrations | Source control & dilution for reaches where flow remains | May be difficult to find markets for salt-tolerant crops |
| In-situ **treatment** (barriers) | Install Reactive Permeable Barrier along both sides of entire length of drain and possibly along all tributary drains | None, should not affect water volumes | Reduces concentrations | None? -- depends on what proportion of the ground-water flow can be intercepted | May be cost prohibitive in agricultural settings; may not need to treat all tributaries/drains to meet the standard |
| In-situ **treatment** (buffer strip concept) | Increase phreatophyte use of ground water where it discharges into the drain | Reduces GW return flows significantly during irrigation season; much less or no winter effect | May increase concentrations significantly in summer, little or no effect in winter | Other remediation measures | Plants may use ground water & leave se in remaining higher conc. ground-water which flows into trib/drain |
| **Dilution** in entire segment | Provide water to the drain by direct deliveries, more canal spills, purchasing water to divert to drain, cloud seeding, etc. | Flows would significantly increase changing the habitat & possibly increasing flooding potential | Reduces; the significance is dependent on how much dilution is provided | Needs source control to reduce volume of dilution needed to a minimum amount | Diversions into the drain is not a beneficial use under CO water law; could cause additional salt/se loading; many concerns |
| **Diversion** | Intercept ground-water prior to entering the trib/drain with perforated pipe or well systems and convey water to the river | Eliminates some portion of ground water entering drain; depending on the extent of coverage, could dewater the drain in winter | Reduces during irrigation season; possibly no change in non-irrigation season, i.e., if some drain flow remains | Treatment or dilution for any remaining un-captured ground-water flowing into the trib/drain | |

## Remedial Alternatives for Meeting Standards

The Task Force's technical subgroup was presented with the question –

> "How can we meet the 4.6 ppb selenium standard in these tributaries/drains?"

Five alternatives were developed which could possibly meet the standard. The alternatives, which are described and evaluated in the following pages, are:

1. Source control with dilution
2. Diversion
3. Permeable reactive barriers
4. Biological treatment with source control and dilution
5. Collection and biological treatment

These alternatives are not displayed in priority order. They all conform to the mission statement of the Task Force which is: "To evaluate, assess and actively address elevated selenium and other adverse water quality issues *while maintaining the area's economic viability, quality of life, and agricultural heritage*." Except for Alternative 2 - Diversion, the alternatives are formulated to maintain, to some degree, some or most of the existing flow in the tributary/drain and thus, preserve the existing aquatic habitat.

### *Alternative 1 - Source Control with Dilution*

This alternative is based on the following assumptions:

- The major sources of ground-water inflow to tributaries/drains are canal/lateral seepage and deep percolation resulting from agricultural, lawn, garden and landscape irrigation.
- It is not possible to completely eliminate seepage and deep percolation, and thus, some level of perennial flow will continue in the tributaries/drains, despite what source-control measures are implemented.

***Description of Alternative 1***

Alternative 1 would implement additional source-control measures in the study area to reduce the amount of delivery-system seepage and deep percolation from irrigation. These measures would use similar technology to what is currently being implemented in the area. For example, it would include lining canals, piping laterals, application of PAM and more on-farm efficiency improvements. This remedial action would reduce the volume of ground-water and the resulting drainage of selenium-contaminated ground-water into each tributary/drain. Tributary/drain flow rates and volumes would be minimized. Dilution would then be provided in sufficient quantities to bring the tributary/drain into compliance with the standard.

Table 3 displays the components of Alternative 1 that are needed to meet the standards along with specific measures to be implemented and other ancillary information. The mix of sources to be controlled varies throughout the valley depending on the degree of urban or suburban development; thus the specific measures used would be selected to fit each tributary/drain situation.

## Table 3 -- Alternative 1 (Source Control with Dilution) Components

| Type of action | Need addressed | Specific Measure | Anticipated Effect | Possibilities for funding/implementation |
|---|---|---|---|---|
| Source control | Reduce/eliminate seepage from irrigation water delivery system | Line/pipe/use PAM on all unlined canals & laterals | Less ground-water inflow to trib/drain | Salinity control programs supplemented by local or other funding |
| Source control | Reduce deep perc from agricultural, lawn, garden, landscape, & pasture irrigation | Provide education, incentives or regulation to homeowners & farmers to incorporate efficiency improvements and xeriscaping | Less ground-water inflow to trib/drain. | NRCS EQIP; Section 319 funding; other water conservation programs; city/county regulations |
| Dilution | Provide dilution flows to bring remaining drainage into compliance with standard | Supplement flows through out the year in tributaries/ drains by additional diversions from Colorado River & from storage | Meet the standard | No identified sources of very significant funding requirement; extreme implementation issues |

### ***Evaluation of Alternative 1***

***Effect of previous source control actions in the Grand Valley:*** Extensive source control actions have been undertaken since 1979 within the study area (north side of the Grand Valley) as part of the Colorado River salinity control efforts by the Department of Agriculture (NRCS) and Department of the Interior (Bureau of Reclamation).

- Under Reclamation's Colorado River Basin Salinity Control Program, approximately $161 million was spent during the period 1980 - 1998 to concrete and membrane line about 47% (21 of 45 total miles) of the Government Highline Canal and pipe 93% (128 of 137 total miles) of the irrigation laterals that it serves.
- Starting in 1979, the SCS/NRCS's salinity control program, EQIP, and other programs have spent approximately $42 million (thru FY03) for on-farm irrigation efficiency improvements. These improvements involved installing underground pipelines, gated pipe, concrete-lined ditches, land leveling and a variety of other practices including drip or micro-sprinkler irrigation.
- The estimated salinity reduction due to all these projects is approximately 218,000 tons annually or about 38% of the total original (pre-project) salt load produced in the Grand Valley.

Significant reductions in salt loading have been observed in the Grand Valley through Bureau of Reclamation and USGS monitoring and studies. These reductions can be attributed to these source control improvements plus land use and associated water use changes. Verification studies completed in Reed Wash drainage near Fruita during the early 1980's showed canal lining and lateral piping reduced salinity loading by 95% from those sources.

Selenium was not monitored during this time, and thus it is difficult to project what effects these projects had on concentrations in any of the tributaries/drains. Similar source-control efforts for the Montrose Arroyo Demonstration project near Montrose showed streamflows were reduced 13% during the non-irrigation season by improvements to the delivery system and overall selenium loading was reduced by 27%. Most people believe that the Grand Valley salinity control projects were effective in also reducing selenium loading.

***Anticipated effects of Alternative 1***

Implementation of additional source control measures under this alternative should lead to a year-around reduction in flow volume in the tributaries/drains and have the following effects:

- Selenium concentrations ***during the irrigation season*** (April through October) should be lower, IF tailwater discharges from on-farm use and administrative spills continue. (Note that on-going water conservation actions are reducing spills where possible in order to provide water for other environmental and human use needs.) Some portions of tributaries/drains may presently or in the future meet the water-quality standard for selenium during the irrigation season without a dilution component.
- Selenium concentrations during the non-irrigation season, may remain the same, be higher, or be lower than the existing condition. A somewhat reduced ground-water discharge (supplemented by infrequent precipitation events) would continue in the tributaries/drains. Data from the Montrose Arroyo Demonstration project showed selenium concentrations actually slightly increased in some parts of that basin where source control measures (piping of unlined laterals) were implemented while other areas decreased significantly. However, the total loading from the Montrose Arroyo drainage decreased due to less seepage being available to mobilize selenium.

Alternative 1 would not meet the selenium standard in the non-irrigation season without dilution, unless source control is able to dry up the entire tributary/drain during that time. This is believed to be unlikely. Therefore, the purpose of source control in Alternative 1 is to reduce the volume of contaminated flow that must be diluted. A target for reducing selenium concentrations might be met solely using much more dilution water with no source control measures, but a much greater volume of dilution water would be needed.

***Dilution*** is the critical element needed to allow Alternative 1 to meet the selenium standard. A cursory analysis (displayed in Table 4) was conducted to examine the potential feasibility of providing the necessary amount of dilution. This analysis was conducted for the 12 identified tributaries/drains on the north side of the river where existing USGS data were available. Calculations were made based on several assumptions which are noted below the table. The analysis identifies the flow rates and seasonal volumes needed to bring the 85$^{th}$ percentile concentration down to the 4.6 ppb selenium standard. It assumes flows (both irrigation and non-irrigation seasons) will be reduced by 10% due to additional source control.

The results of this preliminary analysis show that 274,400 acre-feet of water would be needed for dilution of these 12 tributaries/ drains in the non-irrigation season, and 562,400 acre-feet of water would be needed for 10 (Data are not currently available on two others) tributaries/drains in the irrigation season. When adjusted for the requirements of all 12 tributaries/drains, the total annual need is about 875,000 acre-feet of water. (For purposes of comparison, this is about 117 percent of the active pool of the state’s largest reservoir, Blue Mesa.)

## Table 4 -- Dilution needs for Alternative 1

| Tributary/Drain | Non-Irrigation Season<br>Nov – March (151 days) | | | Irrigation Season<br>April – October (214 days) | | |
|---|---|---|---|---|---|---|
| | 85th Percentile Selenium Concentration | Dilution Requirement Flow (cfs) | Dilution Requirement Volume (AF) | 85th Percentile Selenium Concentration | Dilution Requirement Flow (cfs) | Dilution Requirement Volume (AF) |
| Lewis Wash/Waste | 33 | 0.6 | 200 | < standard | 0 | 0 |
| Indian Wash/Waste | 104 | 31 | 9,300 | 6 | 13 | 5,600 |
| Carpenter/Leach Creek/Drain E | 98 | 221 | 66,100 | 13 | 72 | 30,700 |
| Persigo Wash/Drain G | 81 | 70 | 21,000 | 15 | 93 | 39,500 |
| Prichard Wash/ Drain H | 23 | 8 | 2,500 | n/a | n/a | n/a |
| Hunter Wash/ Drain I | 32 | 19 | 5,700 | 11 | 55 | 23,100 |
| Adobe Creek/ Drain J | 88 | 40 | 12,100 | 14 | 92 | 39,000 |
| Little Salt Wash | 20 | 10 | 3,100 | 6 | 24 | 9,900 |
| Big Salt Wash | 43 | 83 | 24,900 | 18 | 244 | 103,200 |
| Reed Wash/ Drain M | 126 | 226 | 67,600 | 22 | 568 | 240,500 |
| Mack Wash | 54 | 53 | 15,900 | n/a | n/a | n/a |
| Salt Creek near Mack | 64 | 154 | 46,000 | 10 | 167 | 70,700 |
| TOTALS | | 916 | 274,400 | | 1,327 | 562,400 |

Assumptions:

1. Selenium concentration in dilution water is 1 ppb.
2. Flow reduction due to additional source control is 10%.
3. Concentrations remain constant in post source-control flow.

Annual total volume required: 274,400 + 562,400 = 836,800 acre-feet.
Please note that data were not available for 2 tributaries during the irrigation season. Inclusion of these needs would probably increase the total volume requirement by 5 – 6% to about **875,000 acre-feet**.

In order to provide this amount of water, some seasonal direct diversions would be needed, and a large storage reservoir would be required. Operational studies required to size reservoirs are beyond the scope of this study. It is likely that a reservoir the size of Blue Mesa or even larger would be required to provide these dilution volumes. Water availability would driven by senior Grand Valley water rights during the irrigation season (mid-March to early November) and by endangered fish needs in the non-irrigation season. Table 5 identifies many concerns associated with Alternative 1.

# Table 5 - Concerns about delivering dilution flows to the Grand Valley tributaries/drains

1. The Government Highline Canal would need to be enlarged and unlined sections lined or a new parallel lined canal constructed with associated appurtenances (tunnels, checks, turnouts, etc.). Lining would be needed to prevent additional seepage (water inflow to the ground-water system) which would increase salt and selenium loading to the Colorado River.

2. Winter maintenance on the existing Government Highline Canal may be interrupted; sediment removal and repair of structures would be difficult to accomplish.

3. Winter operations of the Grand Valley Project (Cameo) Diversion Dam would be more difficult and costly; winter ice problems with turnouts and effect on canal capacity may be troublesome.

4. Additional volumes of “push” water may be needed to deliver the required flow to the lower reaches of each tributary/drain.

5. A significant new diversion could affect fish and wildlife habitat along the Colorado River and flow recommendations for endangered fish. If diversions were to cause river flows to drop below recommended levels, the US Fish and Wildlife Service (USFWS) and others would have to make a trade-off decision as how best to utilize the available water. (Analysis of Alternative 1 dilution needs assumed fish flows would be met.)

6. Flow recommendations for the endangered fish call for a minimum of 1,630 cfs in the river. Would need to determine how much water would be available in the non-irrigation season.

   When examining the historical flow records, it will be important to note that there is now less water in the river in the winter due to the recent summer releases from storage for the fish. This is a rather recent occurrence, so the historical flow records may forecast something higher than current flows.

7. Additional water rights may be needed and be costly; could a beneficial use right be acquired for water quality improvement?

8. Additional public safety concerns arise from year-round canal operations.

9. Providing dilution to these tributaries/drains would reduce their capacity to convey stormwater, possibly increasing flooding to downstream properties.

10. Selenium concentrations in some portions of the Colorado River through the Grand Valley would increase because “cleaner” dilution waters must be taken from the river above the Grand Valley where selenium concentrations are lower. This may particularly affect the 15-Mile Reach of critical habitat for endangered Colorado pikeminnow and razorback sucker.

11. Dilution flows may create additional erosion and downstream sediment issues in the tributaries/drains as the channels adapt to higher flow rates. Increased velocities and volume may have negative consequences on aquatic and riparian habitat and human safety.

12. Construction of the largest reservoir in Colorado would have immense impacts.

13. Political approval and public acceptance would be difficult.

The total cost of Alternative 1 is estimated in excess of $1.6 billion. This figure includes the costs of additional source-control activities to reduce flow in the tributaries/ drains, a reservoir, and a new canal to deliver dilution water. It does not include the costs of probable relocations of Interstate 70, the railroad, and residential, farm, and commercial properties within the reservoir area. The costs are only rough approximations based on proposed or previously constructed facilities in the Grand Valley area. Annual O&M of the new facilities would be approximately $1.3 million.

***Conclusions regarding Alternative 1***

Upon realization of the vast impacts of providing such a large volume of dilution and all the associated concerns and potential impacts, the Task Force technical subgroup made an early decision that this alternative is infeasible and unreasonable. However, it should be noted that in the case of some very low flow tributaries/drains, it may be physically feasible to store water in off-canal reservoirs or pump from the river to dilute them. This option was not investigated.

It also should be noted that it may be possible to meet the standard or reduce selenium concentrations significantly in certain seasons in some of the lowermost segments of the tributary/drain (within the 100-year flood plain) through dilution with flow taken directly from the river. The NIWQP implemented one similar project at the Colorado River Wildlife Area just east of Grand Junction; however the results of the test were not documented due to NIWQP funding being terminated.

**Summary of Alternative 1**

See Table 6 – Comparison of alternatives (last page of this report)

## *Alternative 2 - Diversion*

***Description***

A majority of the ground-water drainage (return flow) would be collected prior to entering each tributary/drain in a perforated-collector pipeline (Figure 2) installed beneath the drain invert (lowest point). The captured waters would be conveyed directly to the river through this pipeline. The design would incorporate measures to isolate as much of the contaminated ground-water as possible during the irrigation season.

Each pipeline would terminate at a discharge structure constructed on the north bank of the Colorado River. It was assumed that a diffuser (which is sometimes required for point-source mixing zones in the river) would not be required. According to the Colorado Water Quality Control Division (WQCD), agricultural return flows are excluded from the definition of "point source" in the Colorado Discharge Permit System (CDPS) Regulations (Reg. 61). Thus, since the collection pipeline would be intercepting agricultural return flows, no Colorado Discharge Permit System permit would be required by the state.

According to the WQCD, this diversion situation differs from that of a gravel pit along the Colorado River that is in a flow path for agricultural returns. Although the pit may be intercepting some agricultural return flows, dewatering the pit may also be adding pollution to this water before pumping it to the river. Pit construction and mining process activities can add sediment or oil and gasoline from machinery, so the possibility of additional pollution from the pit creates the need for a CDPS permit. Additionally, because dewatering a gravel pit is also a point source discharge from an "industrial activity" using water, a discharge permit is required.

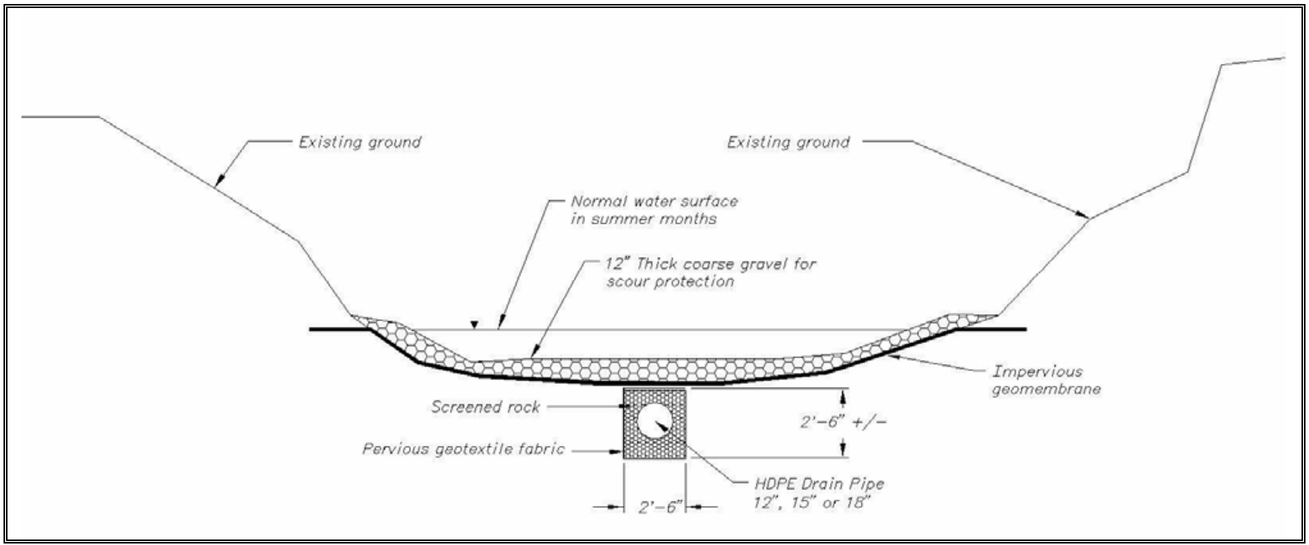


**Figure 2 - Conceptual design of an Adobe Creek/Drain J collector pipeline (not to scale)**

***Evaluation***

Alternative 2 could meet the water quality standard for selenium year-around but would likely adversely affect the existing aquatic and possibly, riparian habitat. It would eliminate all flow in the tributary/drain during the non-irrigation season (November through March) except during and immediately following precipitation events. Mitigation or replacement habitat may be required for this alternative.

During the irrigation season, the flows in the tributary/drain are comprised of administrative spills, surface return flows from irrigation, subsurface (ground-water) return flows from irrigation, and occasionally, precipitation runoff. The collection pipeline envisioned in this alternative would hopefully capture enough of the selenium contaminated ground-water to allow the remaining flow in the drain to meet state standard. A demonstration project could be designed to help identify the specific effects.

The preliminary cost estimate for installation of this diversion system on Adobe Creek/Drain J is $6.1 million or about $162 per linear foot. This estimate includes clearing, pipeline installation, highway, road, and railroad crossings, rights-of-way, contingencies, design, and contracting. Annual O&M costs are estimated at $20-30,000. If the Adobe Creek installation is assumed to be typical and about the same average length of the other 11 tributaries/drains, a rough cost estimate for installation of diversion systems for the 12 tributaries/drains on the north side of the river would be approximately $73 million in initial costs plus $300,000 of annual O&M expense.

**Summary**

See Table 6 – Comparison of alternatives


View of lower reach of existing Adobe Creek/Drain J

## *Alternative 3 - Permeable Reactive Barriers*

***Description***

This alternative would involve installation of Permeable Reactive Barriers (PRB) on both sides of each tributary/drain to remove selenium from ground-water moving toward the drain (see Figure 3). The barrier uses a reactive material such as iron filings that create chemically-reducing conditions so that selenium carried by moving ground-water is de-mobilized. The PRB could be installed in "hot spots" and in phases until sufficient ground-water was treated to bring selenium concentrations in the tributary/drain below the standard.

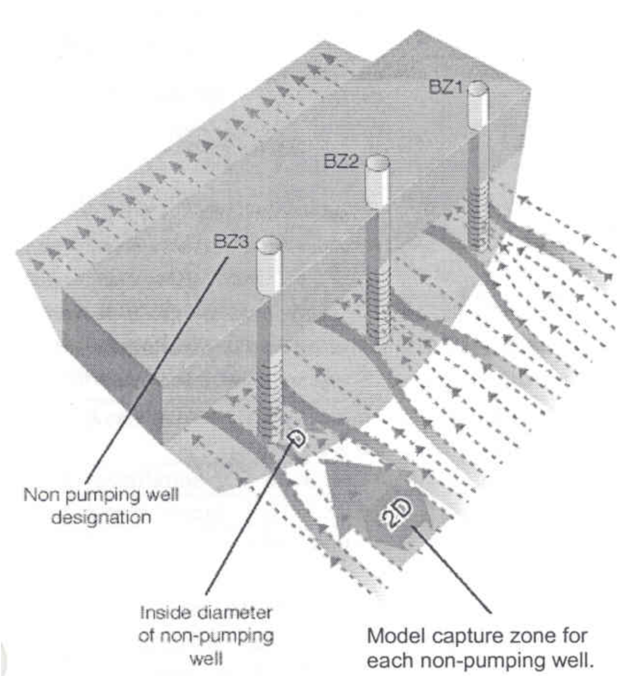


Figure 3 - Schematic showing typical array of wells & contaminant capture zones (courtesy of USGS)

***Evaluation***

A representative project was evaluated for the Adobe Creek/Drain J drainage area. Although the Task Force believes this measure could be very effective, the actual level of effectiveness, i.e., how much selenium could be demobilized, is difficult to predict. If this concept is carried forward, it would be a candidate for an on-the-ground demonstration project to test installation techniques and effectiveness. Land adjacent to Adobe Creek is mostly privately owned. Since access for construction and periodic maintenance would be required along its entire length, it was assumed right-of-way would be acquired in fee title instead of easement.

The Adobe drainage system includes about 7.8 miles of main channel, 2.6 miles of natural-appearing side channels and 7.5 miles of what appear to be man-made drains for a total of 17.9 miles. It was assumed that the entire stream length except for 5% of the very upper reaches would receive treatment along both sides of the channel. Cost information was obtained from work being done by the USGS near Monticello, Utah. The cost estimates include engineering & design, barrier installation, contracting, contingencies, and right-of-way acquisition. Individual estimates were not done for each of the 12 trib/drain system, but it was assumed Adobe was about average length so its figures were multiplied by 12 to obtain a ball park cost estimate for the entire study area.

<u>For the Adobe Cr/Drain J system</u>:

- Initial application = $177 million
- Periodic material regeneration/ replacement at 15-year intervals = $45 million

<u>For the 12 tributaries/drains</u>:

- Initial application = $2.125 billion
- Periodic material regeneration/ replacement at 15-year intervals = $538 million

***Conclusions***

Following the evaluation and discussion of Alternative 3, the Task Force's technical subgroup made a decision that it was not feasible or reasonable to consider this alternative further because of its extreme costs.  However, it was noted that if isolated areas of intense loading ("hot spots") are found during tracer analysis along some of the tributaries/drains, it could be physically feasible and possibly financially feasible to install PRBs.

***Summary***

See Table 6 – Comparison of alternatives

## *Alternative 4 - Biological Treatment with Source Control and Dilution*

***Description***

This alternative is a variation of Alternative 1 that adds biological treatment of a portion of the water in each tributary/drain.

As in Alternative 1, additional source control would be undertaken in the drainage area to remove approximately 10% of the flow and selenium load. Treatment of a portion of the remaining flow would involve the diversion of high selenium flows from each tributary/ drain and treatment of the water in passive selenium-reducing bioreactors prior to being discharged back to the drain. The treatment would be implemented at a level that would reduce selenium concentrations in the lower portion of the tributary/drain by about 50%. The remaining high selenium flow in the drain would be diluted by diversions through an enlarged Government Highline Canal or a new parallel canal as previously discussed in Alternative 1.

Typical Bioreactor Site (Yellow Creek, Pennsylvania)

***Evaluation***

Even though significant source control measures are in place in many of these drainages, it may be possible to reduce additional seepage from unlined canals and ponds and reduce deep percolation. For purposes of this evaluation, it was assumed that additional measures would result in an additional 10% reduction in flow and selenium loading in these drainages. Passive selenium reducing bioreactors are unproven technology but are very similar to proven technology using sulfate-reducing bacteria. A bench-scale test was recently funded by the Bureau of Reclamation. Short detention times of 3 hours have been suggested. It was assumed for purposes of evaluating this alternative, that bioreactor technology would reduce selenium concentrations in the lower portion of the tributary/drain by about 50%.

Even with these measures, dilution is still critical to meeting the water quality standard. A cursory evaluation revealed that about 310,000 acre-feet of dilution water may be needed annually to meet the standard in 12 tributaries/drains (if selenium is reduced by 50% through the use of bioreactors). Some of this water could be provided by direct flow diversions during some portions of the year. However, during the non-irrigation season, flow needs of endangered fish in the 15-Mile Reach would, in many years, require all or most of the available flow. There would also be shortages in the irrigation season during the lower flow months in late summer and early fall. Although water availability studies are beyond the scope of this study, it is anticipated that reservoir storage ranging from a vessel the size of Ruedi Reservoir up to the size of Pueblo Reservoir may be needed to furnish the necessary dilution on a firm basis.

Additionally, a new or enlarged Government Highline Canal would be required to convey dilution water to the heads of the tributaries/drains. It would be anticipated that all of the concerns displayed in Table 5 for Alternative 1 would apply to this alternative.

The total cost of Alternative 4 is estimated in excess of $1 billion. This figure includes the costs of additional water conservation activities to reduce flow in the tributaries/drains, a 300,000 acre-foot reservoir, a new canal to deliver dilution water, and a series of collection and bioreactor treatment systems. It does not include the costs of probable relocations such as Interstate 70, the railroad, and residential, farm, and commercial properties within the reservoir area. The cost of the bioreactor systems are based on information provided by Golder & Associates. The remainder of the costs are rough approximations based on proposed or previously constructed facilities in the Grand Valley area. Annual O&M expenses for the dam and reservoir would be approximately $1,200,000.

***Summary***

See Table 6 – Comparison of alternatives

## *Alternative 5 - Collection & Biological Treatment*

***Description***
This alternative uses a collection system similar to Alternative 2 and adds biological treatment of a portion of the water in each tributary/drain.

As in Alternative 2, a majority of the ground-water system drainage would be collected in a perforated pipeline installed beneath the tributary/drain invert (Figure 2). The design would incorporate measures to isolate as much of the ground-water as possible during the irrigation season.

In the case of Adobe Creek/Drain J, the pipeline would discharge at two locations along the stream into two passive selenium-reducing bioreactors. Once this water was treated in the bioreactor, it would be discharged back to the surface flow in the tributary/drain, providing for the preservation of some of the existing habitat.

***Evaluation***
This alternative could meet the water quality standard for selenium year around in certain sections of the drain, but reduce or eliminate flows in certain portions, possibly adversely affecting the existing aquatic and riparian habitat. As explained in Alternative 4, passive selenium reducing bioreactors are unproven technology. However, for purposes of evaluating this alternative, it was assumed bioreactors would work. If proposed tests (see Alternative 4) prove they are ineffective, other types of biological treatment could be substituted, but costs for the more proven systems would probably be much more expensive (on the order of 4 times or more).

During the *non-irrigation season* (November through March), selenium standards would be met. Flows in the upper reaches of the Adobe Creek/Drain J (above 21 Road) would be eliminated, except during and immediately following precipitation events. In the lower reaches (approximately 70 percent of the trib length), flows may be reduced on the order of 40 to 65 percent. However, runoff events carrying selenium from BLM lands above the Government Highline Canal could still create short periods with selenium concentrations above the water-quality standard.

During the irrigation season, the flows in the tributary/drain are comprised of administrative waste, surface return flows from irrigation, subsurface (ground-water) return flows from irrigation, and occasionally, precipitation runoff. The collection pipeline envisioned in this alternative would be designed to capture enough of the selenium contaminated ground-water to allow the remaining flow in the drain to meet the water-quality standard when treated water from the bioreactors is discharged back to the trib/drain. A demonstration project could be designed to help identify the specific effects.

A preliminary cost estimate for installation of the diversion system on Adobe Creek/Drain J is $6.1 million or about $162 per linear foot. This estimate includes clearing, pipeline installation, highway, road, and railroad crossings, rights-of-way, contingencies, design, and contracting. Two selenium-reducing bioreactors would add about $1.1 million for a total cost of $7.2 million. Annual operation & maintenance costs for the pipeline and treatment systems would be about $72,000.

If one assumes the Adobe Creek installation would be typical and about the same average length of the other 11 tributary/drains, a rough cost estimate for all 12 would be approximately $86 million in initial costs plus $950,000 of annual O&M expense.

***Summary***
See Table 6 – Comparison of alternatives

## Previously Discarded Concepts

During this analysis, many other less feasible concepts along with variations of the alternatives presented above were discussed, considered and discarded by the technical subgroup and planning team. Listed below are some of the concepts eliminated from further consideration during the study process along with the reasoning behind the decisions.

Wetland treatment cells

*Reasons for elimination:*

1. Wetland treatment cells are largely ineffective outside of the growing season during the winter. This corresponds with the local non-irrigation season when selenium concentrations in the tributaries/drains are highest.
2. Reaching the objective of meeting standards could potentially be accomplished more efficiently by using the bioreactor concept, if it proves effective.
3. Concerns about creating an attractive nuisance for waterfowl persist.

Land retirement

*Reasons for elimination:*

1. The Task Force's mission states "actively address elevated selenium and other adverse water quality issues while maintaining the area's economic viability, quality of life, and agricultural heritage." Area-wide land retirement is inconsistent with this mission.
2. Retirement of some portion of the agricultural lands would result in lower flows in tributaries/drains but would not likely reduce selenium concentrations.
3. Retirement of all agricultural lands would not likely be publicly acceptable.
4. Retirement (from agricultural use) of significant portions of the agricultural lands is essentially occurring due to population growth in the area. If population in the Grand Valley doubles during the next 30 years, as predicted, much or most agricultural production will disappear. Opportunities exist to adapt to changing land use and limit water quality impacts by instituting more wise water use concepts. Reducing the amount of current agricultural land available for residential development may increase the pressure to develop lands that have never been irrigated and have a higher selenium loading potential (e.g., Devils Thumb Golf Course).

Pump Colorado River water (from below the Gunnison River confluence) up to the headwaters of each tributary/drain to dilute remaining high concentrations

*Reason for elimination*: Colorado River water exceeds the selenium standard (below the Gunnison confluence) and thus, would not provide the needed dilution. Should concentrations in the river decrease substantially due to additional source control upstream (Gunnison Basin) in the future, this option could be reconsidered.

Small off-canal storage ponds This would involve the installation of ponds adjacent to the Government Highline Canal to store unneeded water (most spills have been eliminated by Grand Valley Water Management except at Highline and Badger Wash) or at the end of the irrigation season for release during the non-irrigation season.

*Reason for elimination*: Storage requirement of ponds needed to provide sufficient dilution volumes and flow and cover evaporation is huge and would only be physically feasible using a large reservoir (300,000 to 1 million acre-feet or more).

## Conclusions & Recommendations

The water quality standards for selenium in the Grand Valley tributaries/drains could be met; however, the costs of remediation would be very high, well beyond the capability of local entities to fund. Table 6 provides a summary of the 5 alternatives considered in this study. Alternatives 2 and 5 appear to be the most cost-effective solutions but may have significant negative impacts on aquatic and riparian life that use these habitats.

The identified improvements to reduce selenium concentrations in the Grand Valley tributaries/drains are potentially physically feasible. However, implementing such improvements is not likely to be financially feasible without large contributions from the Federal or State governments.

Decision-makers should weigh reasonableness, spending priorities, value of the existing habitat, and the benefits of such remedial action. It seems that the ***benefits of any of these remediation alternatives must be much better defined and the significance understood before decisions are made to proceed with further studies of any of these concepts.*** It is recommended that the Grand Valley Selenium Task Force prepare documentation of the potential benefits of actions to reduce selenium concentrations in these tributaries/drains and compare them with the costs and impacts of alternatives presented in this report. There may be opportunities to accrue similar benefits in higher priority locations at a much lower cost.

Further characterization of the tributaries/drains by the USGS as part of an ongoing Section 319 grant will help determine if specific "hot spots" exist. If there are "hot spots," this presents the opportunity to evaluate some additional site-specific alternatives for reducing concentrations in certain reaches.

Finally, all forms of water conservation (source control) resulting in reduced deep percolation and seepage should be strongly encouraged immediately. This should be the first step of any remediation program and also for smart growth. Wise water use will help meet the Colorado River standards particularly if they ever become more restrictive than the current 4.6 ppb level. It should be kept in mind that water conservation will likely reduce flows and thus habitat for biota in many of the tributaries/drains but may not substantially change selenium concentrations.

## Table 6 -- Comparison of Alternatives

| Alt No | Alternative Description | (All alternatives were formulated to meet the 4.6 ppb selenium standard) **Summary of Other Effects** | | **Investment Cost**[1] | **Annual O&M Costs**[1] |
|---|---|---|---|---|---|
| | | **Pros** | **Cons** | (million $'s) | (million $'s) |
| 1 | Source control with dilution | - Decreases load to CO River | - Extreme costs<br>- Major environmental effects of large reservoir construction<br>- Extensive concerns re: winter diversion operations<br>- Reduction in river flows in "Critical Habitat"<br>- Reduction in stormwater capacity in tributaries<br>- Erosion & public safety concerns in tributaries<br>- More concerns - see summary in Table 5 | 1,650+ [2] | 1.3 |
| 2 | Diversion | | - High cost<br>- Elimination of non-irrigation season surface flow over entire length<br>- Impacts of little or no flow in the non-irrigation season on aquatic/riparian habitat | 73 | 0.3 |
| 3 | Permeable Reactive Barriers | - May be suitable for limited applications in "hot spots"<br>- Decreases load to river | - Extreme costs | 2,125 | 20.8 |
| 4 | Biological treatment with source control & dilution | - Decreases load to river | - Extreme costs<br>- Depends on un-proven selenium bioreactor technology<br>- Major environmental effects of large reservoir construction<br>- Extensive concerns re: winter diversion operations<br>- Reduction in river flows in "Critical Habitat"<br>- Reduction in stormwater capacity in tribs<br>- Erosion & public safety concerns in tribs<br>- More concerns - see summary in Table 5 | 1,012+ [2] | 1.2 |
| 5 | Collection & biological treatment | - Decreases load to river | - High cost<br>- Reduced non-irrigation season surface flow over entire trib length<br>- Some impacts to aquatic/riparian habitat in non-irrigation season<br>- Depends on un-proven selenium bioreactor technology | 86 | 0.9 |

[1]Costs are appraisal-level estimates of implementation costs and future O&M costs for all 12 tributaries/drains.
[2] These costs do not include substantial relocation costs for I-70, the railroad, residential, farm, & commercial properties, etc. that would be required.