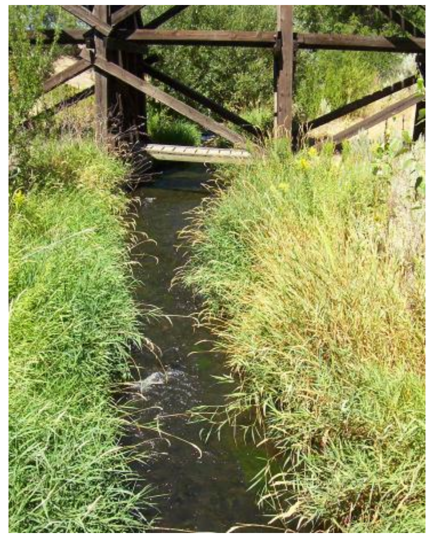
Water Quality Conditions in Irrigation Waterways within the Roza and Sunnyside Valley Irrigation Districts, Lower Yakima Valley, Washington, 1997-2008

Roza-Sunnyside Board of Joint Control

2009

Water Quality Conditions in Irrigation Waterways within the Roza and Sunnyside Valley Irrigation Districts, Lower Yakima Valley, Washington, 1997-2008

by
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Roza-Sunnyside Board of Joint Control

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Acknowledgements

Without support from landowners within our districts, RSBOJC would not have been able to develop or effectively implement a water quality improvement policy and monitoring program. Without financial support from the U.S. Bureau of Reclamation's Pacific Northwest Laboratory, the number of samples analyzed each year would be drastically reduced.

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Front cover photographs (clockwise from upper left): Sulphur Creek Wasteway entering the Yakima River, Snipes Creek Wasteway, Granger Drain, and Sulphur Creek Wasteway.

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Abstract

Water quality conditions in four irrigation waterways – Granger Drain, Sulphur Creek Wasteway, Spring Creek Wasteway, and Snipes Creek Wasteway -- were assessed from 1997 to 2008. During summer months, because much of the water in the lower Yakima River consists of irrigation return flow, the quality of water in the waterways can strongly influence the quality of water in the river. In previous studies, these four waterways were major contributors of total suspended solids to the Yakima River. Concentrations, loads, and yields and potential factors influencing their differences between years and between drainage areas were evaluated. Constituents assessed included total suspended solids, turbidity, fecal coliform, total phosphorus, total Kjeldahl nitrogen, and nitrate+nitrite.

Trends were significantly downward for discharge and concentrations of most constituents during the irrigation season in the four waterways. The largest decreases in concentrations often occurred from 1997 to 2000. Median loads and yields decreased significantly in most waterways. Non-irrigation seasonal median concentrations and loads were variable between years and differences between years were inconsistent between waterways. Half of the non-irrigation trend analyses found no trend and the other half were a mix of upward and downward trends. As irrigation season concentrations declined, the relative importance (concentrations and loads) of the non-irrigation season increased for several constituents. Seasonal and temporal patterns in total Kjeldahl nitrogen concentrations generally were not similar to other constituents.

Of the factors evaluated, the rapid decline in concentrations from 1997 to 2000 could best be explained by improved irrigation practices; however, the variability in water quality improvements between years did not correspond to the variability between years in publicly-funded irrigation improvements of $20,067,033 throughout the lower valley. Possible reasons for the lack of correspondence include an unknown amount of privately-funded improvements that occurred during the same years.

In response to decreased water supplies during two drought years and after a re-regulation reservoir was installed to improve the efficiency of the Sunnyside Canal, total suspended solids concentrations decreased, nitrate+nitrate concentrations increased, and fecal coliform concentrations remained similar. During drought and non-drought years, concentrations of total Kjeldahl nitrogen and total phosphorus remained comparable. After the re-regulation reservoir, concentrations of total Kjeldahl nitrogen increased and total phosphorus decreased or remained similar.

Differences in water quality conditions between waterways during the non-irrigation seasons may have been related to differences in drainage basin characteristics and hydrology. Lower yields during the non-irrigation seasons in Spring Creek Wasteway and Snipes Creek Wasteway compared to Granger Drain and Sulphur Creek Wasteway may have been influenced by the lack of urban areas, coarser drain substrate, more surficial basalt, and lower proportions of the watersheds under irrigation. During the irrigation season, differences in water quality did not correspond as expected to differences in drainage area characteristics. For example, Spring Creek Wasteway and

Granger Drain had similar yields of total phosphorus and total Kjeldahl nitrogen, despite significant differences in crop types, irrigation types, soils, and slopes.

Median yields of fecal coliform, nutrients, and discharge were higher in Sulphur Creek Wasteway than the other waterways during the non-irrigation season, but when a site downstream of the City of Sunnyside was removed from consideration, concentrations of total suspended solids, fecal coliform, and total Kjeldahl nitrogen in Granger and Sulphur sub-drains became comparable. In Sulphur Creek Wasteway, substantial deposition of particulate constituents during the non-irrigation season may result in increased concentrations during the irrigation season as the deposited particles become re-suspended with increased discharge.

Median yields of total suspended solids from the four waterways were similar to other watersheds in the arid West. Estimated annual yields of nutrients tended to be high in Granger Drain and Sulphur Creek Wasteway and moderate-to-low in Spring Creek Wasteway and Snipes Creek Wasteway – less than undeveloped watersheds in some years for total phosphorus. State water quality criteria were frequently exceeded by varying degrees in all four waterways. A 2002 water quality clean-up goal for turbidity was met in three of the four waterways.

Determining the influence of these waterways on the Yakima River was not an objective of this monitoring program. However, available data were reviewed to provide a broader context for the waterway data. The pattern of load reductions of total suspended solids from these four waterways was similar to decreases in turbidity and loads of total suspended solids in the lower river. Total phosphorus concentrations and loads in the lower river did not follow the same pattern as reductions in loads from the waterways but did generally decline. The lower river consistently met water quality criteria for fecal coliform from 2000 to 2008 at the only site routinely monitored by the Department of Ecology; however, because that site is located many miles downstream of the waterways, its usefulness as an indicator of influence was limited. Water temperatures in Spring Creek Wasteway and Snipes Creek Wasteway were cooler than the Yakima River during the summer and warmer during the winter; the amount of influence on the river was calculated to be slight.

To continue improving water quality in these waterways, a better understanding of several influences may be beneficial, including: factors which result in generally better water quality in Snipes, factors influencing spatial variability in nitrate+nitrite concentrations, processes occurring in the urban areas, and the relationship between irrigation and non-irrigation season conditions.

Introduction

Purpose of report, setting

The Roza-Sunnyside Board of Joint Control (RSBOJC) was formed in 1996 to address overlapping responsibilities and concerns of two major irrigation water districts (the Roza Irrigation District and Sunnyside Division) in the lower Yakima Valley. One of the joint concerns was responding to water quality issues in irrigation waterways. In 1997, RSBOJC developed a water quality improvement program, established an in-house water quality laboratory, and began a long-term sampling program of irrigation waterways. This report summarizes the first 12 years of water quality data, from 1997 through 2008. The purposes of the report are to assess changes over the 12-year period, evaluate factors influencing water quality, and provide direction for future water quality improvement efforts.

Agricultural production on the 464,000 acres of irrigated acres within the Yakima Basin in south-central Washington is annually worth $1.3 billion (Scott *et al*, 2004). Irrigation water is provided by five major reservoirs in the Cascade Mountains. The total capacity of the reservoirs, 1,065,400 acre-feet (ac-ft), provides 40% of the 2,490,755 ac-ft of the April to October water users' entitlements (Economic and Engineering Services, Inc., 2003); snowpack and precipitation in the Cascade Mountains supply most of the remainder. The mean annual run-off of the Yakima River varies greatly; for example, 1.3 million ac-ft in 1977, the lowest water-year on record, and 4.4 million ac-ft in the abundant water year of 1999. Diversions are equivalent to about 60% of the mean annual flow (Fuhrer *et al,* 2004). The mean annual irrigation diversion from 1961 to 1990 was 2.2 million ac-ft (USBR, 2002). Mean annual streamflow from 1961 to 1985 was 2.6 million ac-ft at Kiona (Rinella *et al*, 1992). Irrigation waterways strongly influence water quality in the lower Yakima River because they contribute as much as 80 to 90% of the flow in the lower river during the summer (Morace *et al*, 1999).

The lower Yakima Valley, south of Union Gap, is semi-arid with a mean annual precipitation of 6.8 inches (Western Regional Climate Center, 2009). The three largest irrigation providers in the lower valley are the Sunnyside Division, Roza Irrigation District, and Wapato Irrigation Project (for irrigators within the Yakama Indian Reservation). The Roza Irrigation District (Roza) serves 72,500 acres of junior water-right holders at higher elevations on the north slopes of the valley. The Sunnyside Division (Sunnyside) serves 99,244 acres of primarily senior water-right holders on the valley floor and lower slopes (figure 1). Diverse crops are grown in both districts but in 1995 tree fruits dominated the Roza and forage crops dominated the Sunnyside (CH2M Hill, 1998). In 2002, Yakima County ranked first statewide for apple, milk, hop, and grape production and first nationally for apple and hop production (National Agricultural Statistical Service, 2002). Roza diverts water from the Yakima River upstream of the City of Selah into a 94.8-mile canal; Sunnyside diverts near Parker into a 60-mile canal. Both canals end near Benton City. From the canals, water is delivered through 709 miles of laterals to over 5,300 individual deliveries (CH2M Hill, 1998). Diversions usually begin in March to prime the canal system and cease in mid-October. On-farm deliveries typically begin in early April.

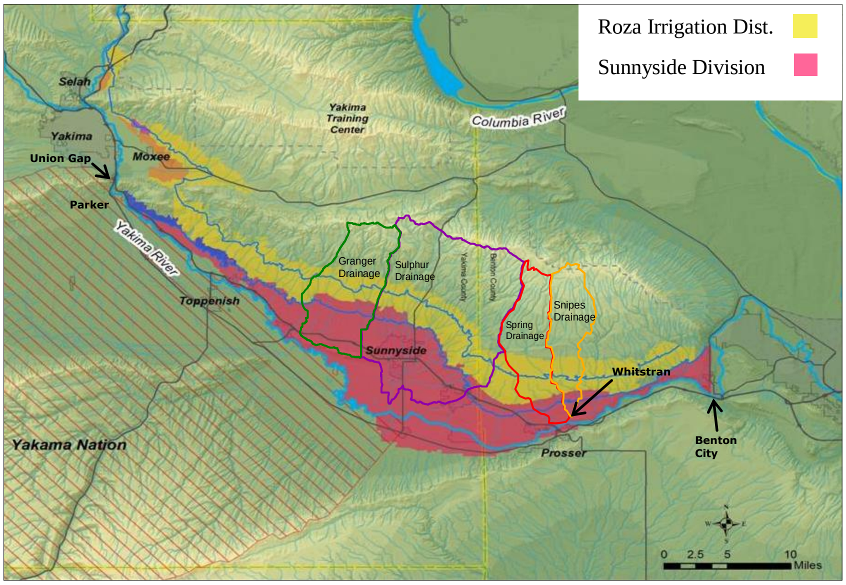


Figure 1. Sunnyside Division and Roza Irrigation District jurisdictions.

Water delivered to individual users is applied to crops and pastures primarily through sprinkler or furrow (known locally as rill) systems. Water is transported off-farm primarily through evapotranspiration, surface run-off, and leaching past the rooting zone. An extensive network of drains returns non-consumed water to the river.

Drains vary substantially in size. Larger drains were designed and constructed in the early 1900's to intercept shallow groundwater to avoid loss of crop productivity due to wet or saline soils (Poe, 1961 and Rice, 2001). Larger drains have discharges of roughly 10-50 cubic feet per second (cfs), water depths of 1-4 feet, and receive water from thousands of acres. Smaller drains have discharges of roughly 1-5 cfs, water depths of less than one foot, and receive water from hundreds of acres.

Water availability

The amount of irrigation water available for use by irrigators varies yearly dependent on the seniority of their water right and snowpack in the Cascade Mountains. In 2001 and 2005, low snowpacks resulted in decreased diversions (figure 2): Roza received 38 and 41% of their water allotment and Sunnyside received 85% for both years (personal communication, Don Schramm, Sunnyside Division, January 2009, and Wayne Sonnichsen, Roza Irrigation District, December 2008).

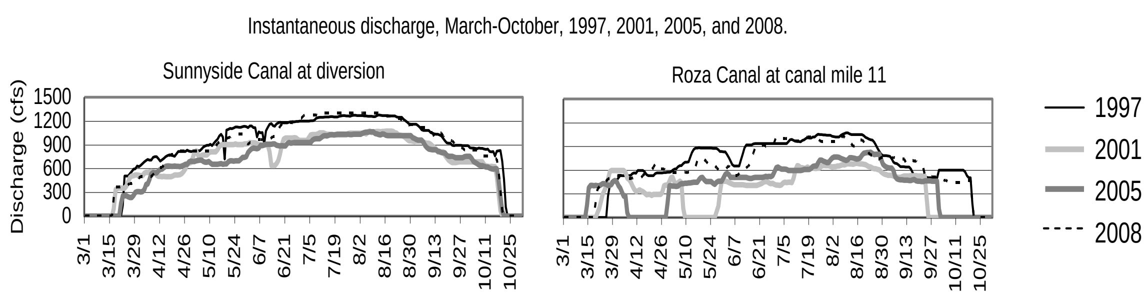


Figure 2. Daily mean discharge at canal diversions, USBR data, March to October 1997, 2001, 2005, and 2008.

Precipitation and air temperature

Seasonal precipitation and mean air temperatures during the 12 years covered by this report did not vary widely between years. The seasonal mean and maximum daily air temperatures varied no more than 3.5 degrees Fahrenheit between years. The seasonal mean precipitation from 1997 to 2008 was 2.1 inches during the irrigation season and 5.1 inches during the non-irrigation season. Precipitation during the 1999 and 2002 irrigation seasons was roughly one inch below the mean and during 2004 was roughly one inch above the mean (figure 3). Of the non-irrigation seasons, 2000 and 2004 had the least precipitation at 3.4 and 2.4 inches, respectively.

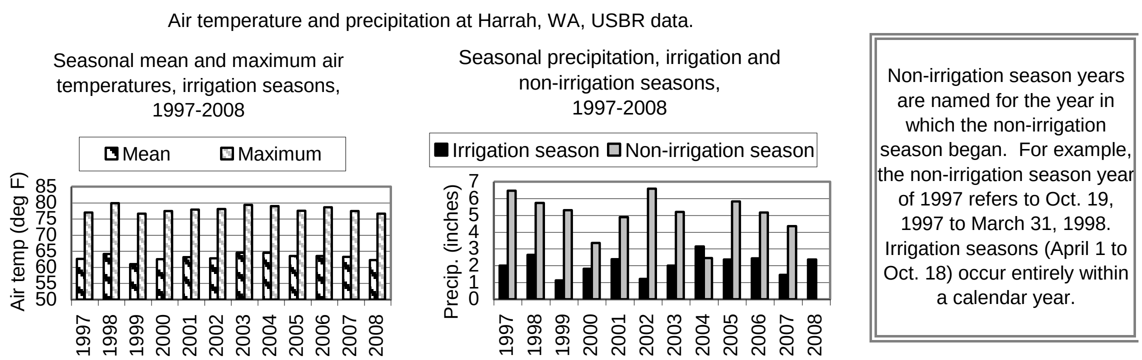


Figure 3. Mean and maximum seasonal air temperatures, 1997 to 2008 irrigation seasons, and seasonal precipitation, 1997 to 2008 irrigation and non-irrigation seasons.

Water quality studies usually focus on irrigation water transport and its role in surface water quality rather than precipitation-driven processes because, in contrast to the minimal precipitation in the area, an average of 36 inches of irrigation water is needed by crops commonly grown (alfalfa, pasture, apples, cherries, grapes, hops, mint, and field corn) in the Sunnyside area (USDA, 1997). Precipitation was evaluated in this report for the sake of thoroughness and because infrequent extreme events have influenced water quality in the past.

Granger, Sulphur, Spring, and Snipes

This report focuses on Granger Drain, Sulphur Creek Wasteway, Spring Creek Wasteway, and Snipes Creek Wasteway – all of which were identified in 1995 as major contributors of suspended solids in the Department of Ecology's clean-up plan for the lower Yakima River (Joy and Patterson, 1997). The estimated and measured contributions of suspended solids from smaller drains managed by RSBOJC were small in comparison to these four major waterways (Joy and Patterson, 1997, and Zuroske, 2006). For ease of reference, this report will refer to these four waterways as Granger, Sulphur, Spring, and Snipes. The term 'waterways' is used throughout the report, except in the literature review, to refer to drains and wasteways.

Sulphur, Spring, and Snipes all function as wasteways in addition to collecting irrigation return flows. Wasteways return canal water to the river from routine canal operations (termed 'operational spill') necessary to maintain water levels in different portions of the

delivery system or during emergency situations such as breaks in the canal. Snipes receives spills from the Roza Canal, Spring from the Sunnyside Canal, and Sulphur from both canals. During the irrigation season, water in Sulphur, Spring and Snipes is a mixture of return flows, operational spill, and groundwater, while in Granger it is a mixture of return flows and groundwater. In July 2005 a re-regulation reservoir was installed near Prosser which significantly reduced spills from the Sunnyside Canal into Spring in subsequent years. During the non-irrigation season the waterways contain mostly groundwater.

Waterway and drainage area characteristics were similar between Granger and Sulphur and between Spring and Snipes but not between Granger/Sulphur and Spring/Snipes. Romey and Cramer (2001) found the excavated drain channels of the Granger and Sulphur systems flowed through silt and sand deposits, with low gradients (0.3-0.4%) and were dominated by glides (65-68%) and mud substrate. Further, Spring and Snipes, located in natural gullies, had gradients of 1%, flowed through basalt geology, and were dominated by riffles (68-75%). Lastly, numerous beaver ponds were found in Snipes. Spring and Snipes converge into a single channel roughly 500 feet before entering the Yakima River.

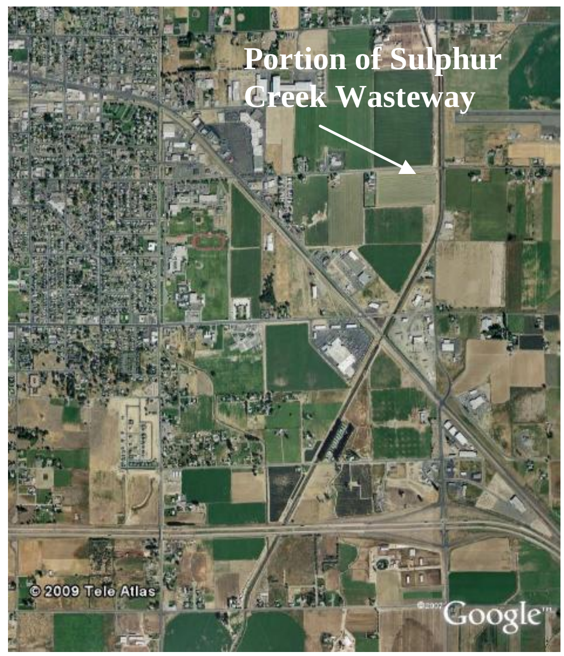
Spring and Snipes drainage areas had lower proportions of rill (furrow) irrigation, higher proportions of drip irrigation, and lower proportions of the entire drainage area under irrigation. Crop types tended to be more similar than different, especially considering the high uncertainty in survey results: three surveys of the Granger drainage area by different organizations found differences of up to 11% in a given crop within a four-year period (Zuroske, 2004).

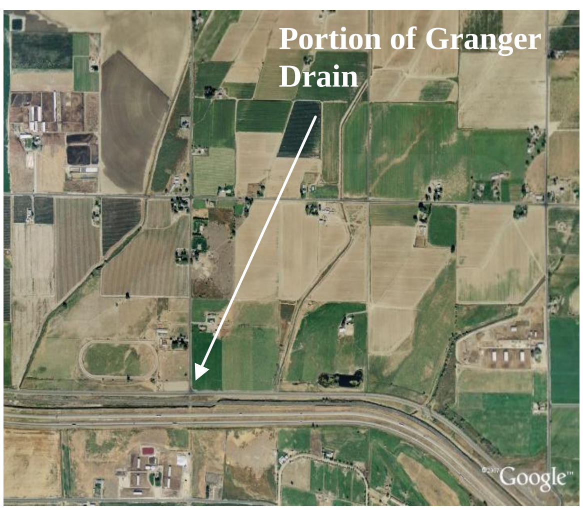
Table 1. Drainage basin characteristics.

<table>
<tr><th>Drainage</th><th>Irrigated acres</th><th>Total acres</th><th>Total square miles</th><th>% of total acres under irrigation</th><th>Dominant substrate in drain (1)</th><th>Drain gradient (%) (1)</th><th>Major crops (2,4)</th><th>Dominant irrigation system (2,4)</th><th>Soils (3,4)</th></tr>
<tr><td>Granger</td><td>26,100</td><td>39,600</td><td>62</td><td>66</td><td>Silt, sand</td><td>0.3</td><td>27% tree fruit, 25% corn, 19% pasture, 11% grapes</td><td>54% sprinkler, 41% rill, 5% drip</td><td>90% silt loam (irrigated portion)</td></tr>
<tr><td>Sulphur</td><td>49,810</td><td>102,730</td><td>161</td><td>48</td><td>Silt, sand</td><td>0.3</td><td>25% pasture, 23% grapes, 17% tree fruit, 11% corn</td><td>48% sprinkler, 40% rill, 3% drip</td><td>57% silt loam, 20% fine sandy loam (irrigated portion)</td></tr>
<tr><td>Spring</td><td>10,920</td><td>27,490</td><td>43</td><td>40</td><td>Gravel, cobble</td><td>0.9</td><td rowspan="2">33% grapes, 27% tree fruit, 17% pasture, 14% hops</td><td rowspan="2">51% sprinkler, 29% rill, 21% drip</td><td>87% high permeability deposits, 13% basalt</td></tr>
<tr><td>Snipes</td><td>5,620</td><td>22,200</td><td>35</td><td>25</td><td>Gravel, cobble</td><td>1.0</td><td>80% high permeability deposits, 20% basalt</td></tr>
</table>

Sources: (1) Romey, 2001; (2) RSBOJC (unpublished data, 2000), (3) Smith, 2006; and (4) Zuroske, 2006.

The combined acres of these four drainage areas represent roughly 10% of the total acres and 34% of the irrigated acres within the lower Yakima Basin.





Previous studies

Past studies relating to water quality in irrigation waterways in the Yakima Basin have assessed general conditions, explored cause-and-effect relationships, identified fate and transport mechanisms, and evaluated changes over time.

An early study by Carlile *et a*l (1974) found the elevated suspended solid concentrations in surface waters were a result of eroding fields, not in-channel erosion. They reported, canal waters "….often carry such a heavy sediment load that untreated water is unsuitable

for irrigation. Some farmers have constructed silting basins in an attempt to remove enough of the particulate matter to render the water fit for use." The authors suggested the use of flocculants might be effective at reducing suspended solids from furrow-irrigated crops. A state-wide study of irrigation return flow management concluded that the "main effects of agricultural activities are high suspended sediment, phosphate, and nitrate concentrations."(CH2M Hill, 1975). Evapotranspiration and leaching were identified as the primary mechanisms responsible for increased salt concentrations in irrigation return flows and thus the Yakima River (Poe, 1961; Glover, 1980).

In a 1976-77 study of Sulphur, Boucher and Fretwell (1982) found: (a) differences in sediment yields (pounds per acre per day) between sub-basins related to slope; (b) constituent concentrations and discharge followed an annual cyclic pattern; (c) the spillway had a diluting effect in Sulphur; and (d) a net change of 10% in sediment discharge from the basin would be needed to be detectable. Based on 2,753 samples of settleable solids in on-farm runoff collected in the Yakima Basin during the 1978-80 irrigation seasons, the Department of Ecology (1982) found: (a) differences between years were not significant (despite significant differences in water availability); (b) April had higher and August had lower settleable solids than other months; (c) steeper slopes were associated with increased settleable solids until slopes exceeded eight percent; and (d) row crops and orchards produced equivalent settleable solids.

In a review of available data through 1985, flow-adjusted trends for 1974-81 were downward for turbidity in Granger and Sulphur, upward for flow in Granger, and downward for suspended sediment and flow in Sulphur (Rinella *et al*, 1992).

From 1987-1991, agricultural drains were determined to be significant sources of nutrients, suspended sediment, pesticides, and fecal coliform bacteria to the mid and lower Yakima River (Morace *et al*, 1999). Drains on the east side of the lower river had 5-fold (5x) or greater suspended sediment loads in June 1989 than other drains due to highly erosive soils, steeper slopes, and rill irrigation (*ibid*). In 1995, Sulphur, Granger, and Spring/Snipes accounted for 18.8, 10.3, and 8.0%, respectively, of the total suspended solids load in the Parker-to-Kiona reach of the river from March through October (Joy and Patterson, 1997). In 2003, Ecology reevaluated the lower river but was unable to complete a revised mass balance due to missing data from the cooperating organizations that collected data from drains within the Yakama Nation. Ecology found the mean total suspended solids irrigation season load in Granger decreased 81% (from 62 tons per day in 1995 to 12 tons per day in 2003) and loads in the Yakima River at Kiona decreased 67% (from 546 to 176 tons per day) at comparable discharges (Coffin *et al*, 2006).

Nutrient concentrations in tributaries were found to decrease in years with ample water supply because low-nutrient canal water made up a higher proportion of water in the tributaries (Ebbert *et al*, 2003). During non-irrigation seasons, total nitrogen concentrations increased because nitrate continued to enter tributaries from subsurface drains and shallow groundwater while suspended sediment and total phosphorus decreased since they were transported to the tributaries in agricultural runoff (*ibid*).

Analyzing RSBOJC's data from 1997 to 2002 in Sulphur and Granger, no correlation was found between percent decline in total suspended solids concentrations and implementation rates of irrigation improvement practices (Zuroske, 2004).

A study of five agricultural basins in the U.S., including a Granger sub-drain, found while the amount of irrigated water applied in arid areas may be similar to precipitation amounts in humid areas, the effect on agricultural chemical transport was not the same (Domagalski *et al*, 2008). A linked article concluded that small, pristine low-nitrogen streams were more effective at nitrogen processing and retention than streams in agricultural regions where nitrogen concentrations are high, riparian vegetation reduced, and riparian flowpaths often bypassed by tile drainage (Duff *et al*, 2008).

Methods

The number and location of sites which were routinely sampled varied during these years but generally included canals, waterways, and secondary drains (figure 4). The major waterways -- Granger, Sulphur, Spring, and Snipes -- were sampled near their mouths in each year. Secondary drains were sampled from 1997 through 2005 in the Granger system and 1999 through 2005 in the Sulphur system.

Sampling frequency also varied (table 2). The most common frequency was to sample twice per month during the irrigation season, April 1 – October 18, and once per month during the non-irrigation season, October 19 – March 30.

Table 2. Sampling frequency.

<table>
<tr><th>Location</th><th>1997</th><th>1998</th><th>1999</th><th>2000</th><th>2001</th><th>2002</th><th>2003</th><th>2004</th><th>2005</th><th>2006</th><th>2007</th><th>2008</th></tr>
<tr><td>Sulphur</td><td colspan="12">Semimonthly (semi)</td></tr>
<tr><td>Sulphur sub-drains</td><td colspan="2">Not sampled</td><td colspan="2">Semimonthly</td><td>Monthly</td><td colspan="4">Semimonthly</td><td colspan="3">Not sampled</td></tr>
<tr><td>Granger</td><td colspan="6">Semimonthly</td><td colspan="2">Weekly</td><td>Semi</td><td colspan="3">Weekly</td></tr>
<tr><td>Granger sub-drains</td><td colspan="4">Semimonthly</td><td>Monthly</td><td colspan="4">Semimonthly</td><td colspan="3">Not sampled</td></tr>
<tr><td>Spring</td><td colspan="12">Semimonthly</td></tr>
<tr><td>Snipes</td><td colspan="12">Semimonthly</td></tr>
<tr><td>Roza Canal nr diversion</td><td>Not sampled</td><td colspan="3">Semimonthly</td><td colspan="4">Monthly</td><td>Variable</td><td colspan="3">Semimonthly</td></tr>
<tr><td>Sunnyside Canal nr diversion</td><td>Not sampled</td><td colspan="3">Semimonthly</td><td colspan="4">Monthly</td><td>Variable</td><td colspan="3">Semimonthly</td></tr>
<tr><td></td><td colspan="12">Non-irrigation Season</td></tr>
<tr><td></td><td>1997-98</td><td>1998-99</td><td>1999-00</td><td>2000-01</td><td>2001-02</td><td>2002-03</td><td>2003-04</td><td>2004-05</td><td>2005-06</td><td>2006-07</td><td>2007-08</td><td></td></tr>
<tr><td>Sulphur</td><td colspan="11">Monthly</td><td></td></tr>
<tr><td>Sulphur sub-drains</td><td colspan="2">Not sampled</td><td colspan="7">Monthly</td><td colspan="2">Not sampled</td><td></td></tr>
<tr><td>Granger</td><td>Monthly</td><td>Semi</td><td colspan="3">Monthly</td><td colspan="2">Weekly</td><td>Semi</td><td>Monthly</td><td colspan="2">Variable</td><td></td></tr>
<tr><td>Granger sub-drains</td><td colspan="9">Monthly</td><td colspan="2">Not sampled</td><td></td></tr>
<tr><td>Spring</td><td colspan="11">Monthly</td><td></td></tr>
<tr><td>Snipes</td><td colspan="11">Monthly</td><td></td></tr>
</table>

At most sites in most years parameters included the following: (1) total suspended solids, turbidity, and fecal coliform analyzed by RSBOJC's in-house lab accredited by the Department of Ecology; (2) total phosphorus, nitrate+nitrite, and total Kjeldahl nitrogen analyzed by the United States Bureau of Reclamation's (USBR) Pacific Northwest Laboratory in Boise, Idaho; (3) dissolved oxygen, pH, temperature, and specific conductance measured *in situ*, and (4) instantaneous discharge. Parameters sampled less often were *E. coli*, ammonia, orthophosphate, and silicon. Total dissolved solids analyses were not conducted; instead, specific conductance values were multiplied by a conversion factor of 0.65 to estimate total dissolved solid concentrations (Rinella *et al*, 1992).

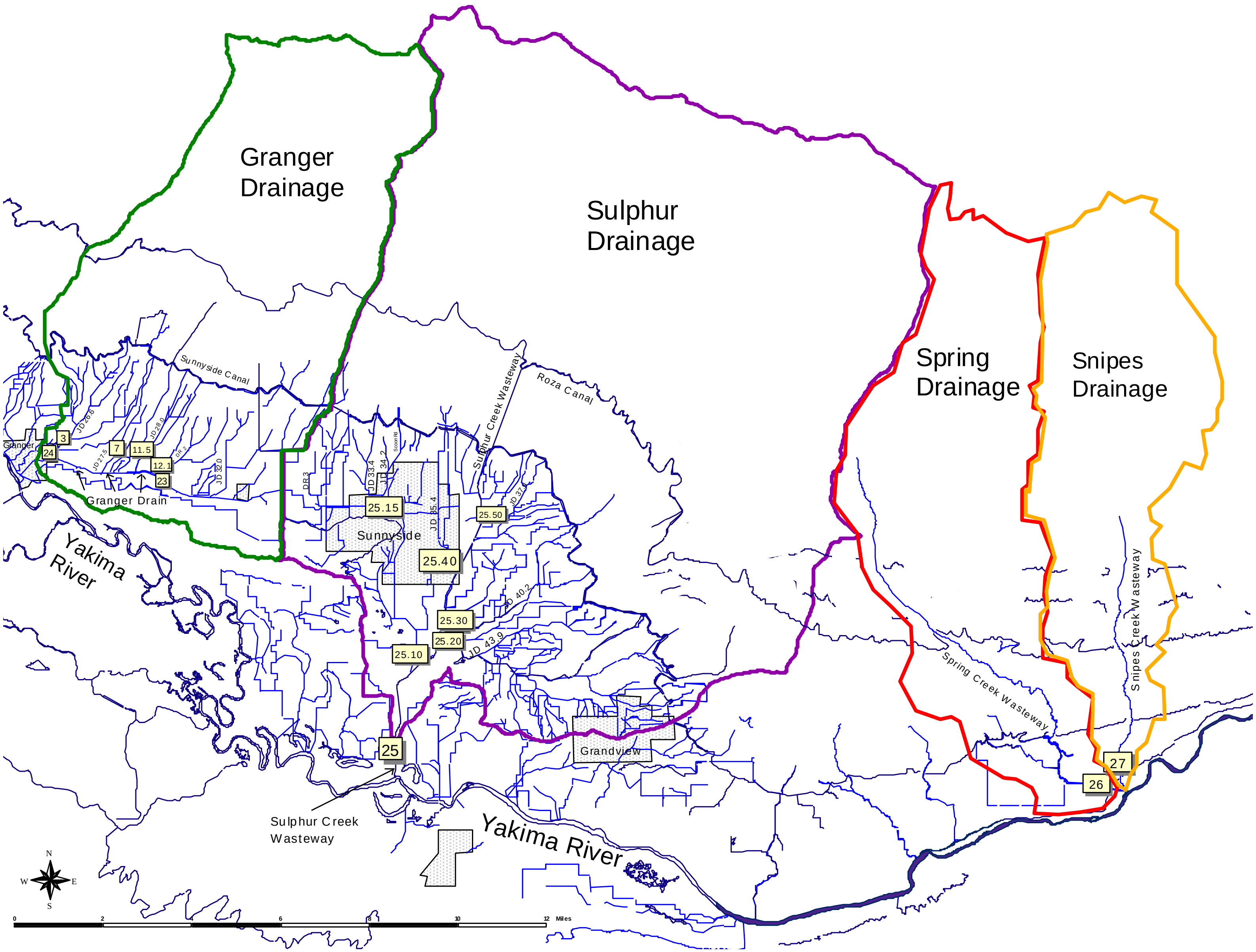


Figure 4. Approximate location of select sampling sites.

Equal-width-depth integrated samples of nutrients, turbidity, and total suspended solids were collected using a US DH-81 for wadeable drains or US DH-59 for bridge mounted access. Grab sampling was used to obtain fecal coliform samples. Sample containers were stored on ice in the field, then transferred to a refrigerator until analyzed in-house or shipped on ice for next-day delivery to Boise.

Water velocity and depth were measured with a Swoffer 3000 meter and top-set rod. At frequently-visited sites, vertically-adjustable Nu-Way ramp flumes were installed to measure discharge. At other sites, staff gages were used to develop rating curves. Rating curves were initially derived by hand using french curves but in later years were derived by fitting the best possible regression line to the data using Microsoft Excel.

Instantaneous loads were calculated for total suspended solids, nutrients, and total dissolved solids using the standard formula of *concentration (mg/L) x discharge (cfs) x 5.386 (conversion factor) = pounds per day*. Because fecal coliform bacteria do not have an easily measurable mass, the following surrogate measure of rate was used: *concentration (col/100 mL) x discharge (cfs) x 283.2 (283.2 deciliters in a cubic foot) = colonies per second*.

Yields were calculated by dividing the instantaneous load by the acres within a drainage area. Where secondary drains discharged into canals instead of the main waterway, the acres served by the secondary drain were not included in the drainage area for parameters transported primarily by surface water -- total suspended solids, total Kjeldahl nitrogen, total phosphorus[1], and fecal coliform. All irrigated acres within a drainage area were included to calculate nitrate and discharge yields.

To estimate seasonal loads of total suspended solids delivered from the canals to a specific drainage area and the seasonal load leaving that drainage area, the following approach was used. The years of 1997-99 were not evaluated due to rapidly changing concentrations in the waterways. After 1999, the only years with concentration data for canals sites near their entry to the drainages were 2000 and 2004. For those two years, the concentration of total suspended solids in canal water was multiplied by the mean amount of water delivered per acre, the number of irrigated areas in the drainage area, and the standard conversion factor of 5.386 to obtain a load. The mean water delivered per acre was calculated to be 0.00756 cfs per acre per day based on a mean 3 ac-ft per acre delivered during the 200-day irrigation season.

Trends were evaluated using the Seasonal Kendall trend test which accounts for seasonality by computing the Mann-Kendall test on each season separately and then combining the results. In this report, each month was considered a separate season. The Mann-Kendall test is a non-parametric test to determine whether values (typically medians) tend to increase or decrease over time (Helsel and Hirsh, 2000).

Methods used to determine whether differences between values were meaningful are discussed in the quality assurance section, below.

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[1] Although total phosphorus includes dissolved forms of phosphorus, the strong relationship between total phosphorus and total suspended solids in these data suggested it is still primarily transported by surface water.

Quality assurance

The results from the quality control samples show generally excellent-to-good quality data. RSBOJC's data quality objective was to maintain or improve the level of precision and bias established in their June 1999 Lab Quality Assurance Manual (table 3), which were established by calculating the median and 90th percentile relative percent differences (RPDs) of field and lab duplicates analyzed to date (Rice, 1999). Data quality objectives for total suspended solids and fecal coliform were met while the objectives for turbidity and total phosphorus were not met in 3% and 8% of the replicate samples, respectively.

Table 3. Analytical method, detection limit, data quality objective, and field replicate results.

Parameter	Analytical Method	Lab	Detection Limit	RSBOJC Data Quality Objective	Results, field replicate samples, 1997-2008	
					n	90th percentile RPD
Total suspended solids	SM2540D	RSBOJC	1 mg/L	90th percentile RPD ≤ 10% or ± 3 S.D.	364	10%
Turbidity	SM2130B *	RSBOJC	0.5 NTU	90th percentile RPD ≤ 4% or ± 3 S.D.	368	6%
Fecal coliform	SM 9222D *	RSBOJC	1 col/100 mL	RPD ≤40%	409	36%
Nitrate+nitrite	EPA 353.2	USBR	0.01 mg/L	RPD ≤ 2%	369	2%
Total Kjeldahl nitrogen	EPA 351.2	USBR	0.03 mg/L	RPD ≤13%	369	9%
Total phosphorus	EPA 365.1	USBR	0.01 mg/L	RPD ≤ 9%	369	14%

* Representative sub-samples are obtained by vigorous stirring of environmental samples with a magnetic stirrer and stirring bar. A wide-bore pipet (25 mL) is used to obtain a vertically integrated sub-sample.

Ninety percent of the 18 replicate discharge measurements (taken in waterways other than Sulphur, for which RSBOJC relies on USBR discharge data) had a RPD of four percent or less and an absolute difference of 0.4 cfs or less.

In addition to field replicates, RSBOJC routinely performed lab replicates, which consistently had lower RPDs than the field replicates. The 90th percentile RPDs for lab replicates were 3.4% turbidity, 33% fecal coliform, and 5% total suspended solids; the 90th percentile absolute differences were 2.0 NTU, 390 colonies fecal coliform, and 6.0 mg/L total suspended solids.

Based on the following, a conservative estimate of uncertainty in RSBOJC total suspended solids analyses from 1997 to 2008 was 3 milligrams per liter (mg/L). Out of 89 total suspended solids results reported as negative values, 90% were -3.0 milligrams or less. Of the field blanks, 90% of the positive blanks had 1.4 mg/L or less and 90% of the negative blanks had -2.3 mg/L or less.

Out of 920 fecal coliform equipment blanks and 918 procedural blanks, all of the samples had zero fecal coliform reported.

RSBOJC did not set data quality objectives in their 1999 Lab Quality Assurance Manual for dissolved oxygen, pH, temperature or specific conductance. The 90th percentile relative

percent differences between field replicates of each parameter, in order, were 0.8, 1, 1.5, and 0.5% and the 90th percentile absolute differences were 0.09 mg/L, 0.08 standard units, 0.2 º C, and 1.5 uS/cm.

From 1997 to 2008, a total of 27,699 quality control analyses were performed by USBR on batches associated with RSBOJC samples. Nitrate+nitrite analyses had the highest precision, as indicated by relative percent differences between replicates (table 4). Lower precision for total Kjeldahl nitrogen would be expected since the method includes analyses of organic compounds. Accuracy was well within the laboratory's objective of 85 to 115 percent recovery for more than 90% of the samples. Out of 1,984 blank samples analyzed for nitrate+nitrite, less than 8% (149) had detections, of which 114 (77%) were at the detection limit of 0.01 mg/L, 24 were at 0.02 mg/L, three were at 0.03 gm/L, four were at 0.04 mg/L, one was at 0.05 mg/L, and two were at 0.08 mg/L.

Table 4. USBR quality control samples.

Percent recovery	Spikes					Knowns				
	n	Range	Median	90th Percentile	10th Percentile	n	Range	Median	90th Percentile	10th Percentile
Nitrate+nitrite	2843	1 to 205	99	102	96	4004	2 to 262	100	106	97
Total phosphorus	2638	75 to 116	100	103	97	1004	83 to 813	100	102	98
Total Kjeldahl nitrogen	2307	25 to 133	100	106	96	1554	91 to 1300	100	102	97

Duplicates		Relative percent difference			Absolute differences (mg/L)		
	n	Range	Median	90th Percentile	Range	Median	90th Percentile
Nitrate+nitrite	2844	0 to 196	0.2	6.9	0 to 4.35	0.010	0.050
Total phosphorus	2650	0 to 166	2.7	10.0	0 to 2.16	0.002	0.010
Total Kjeldahl nitrogen	2277	0 to 192	3.9	15.4	0 to 1.51	0.000	0.000

In this report, the amount of difference needed for two values to be meaningfully different are those differences larger than the uncertainty in the data; specifically, when comparing discrete values, larger than 90% of the differences between field replicates, and when comparing median values, larger than 50% of the differences between field replicates (table 5). The difference between absolute values was used as an indicator of uncertainty for values within 5x the detection limit, while the relative percent difference was used for values greater than 5x the detection limit (USBR, 2002). The smallest meaningful differences were for turbidity values and nitrate concentrations and the largest for fecal coliform concentrations. Fecal coliform variability is inherently high in natural systems and would be expected to have larger differences necessary to be meaningfully different.

When comparing groups of data, differences were considered to be meaningful when the median of one distribution was greater than the 75th percentile or less than the 25 percentile of another site or season's distribution. This conservative measure of difference was used for three reasons: (1) the lack of software which could perform non-parametric measures of statistical significance such as the Wilcoxon rank-sum test; (2) an attempt to indicate environmentally significant changes, not just changes that were statistically significant; and (3) ensuring differences were greater than the uncertainty in the data.

Table 5. Meaningful differences.

	Meaningful differences between **discrete** values: at least as much as the differences between 90% of field replicates.		Meaningful differences between **median** values: at least as much as the differences between 50% of field replicates.	
Parameter	**Absolute difference**	**Relative percent difference**	**Absolute difference**	**Relative percent difference**
Total suspended solids	16 mg/L	10%	2.8 mg/L	3%
Turbidity	4 NTU	6%	0.5 NTU	2%
Fecal coliform	500 col/100 mL	36%	70 col/100 mL	15%
Nitrate+nitrite	0.08 mg/L	2%	0.02 mg/L	1%
Total Kjeldahl nitrogen	0.09 mg/L	14%	0.03 mg/L	5%
Total phosphorus	0.04 mg/L	9%	0.01 mg/L	3%
Discharge (except Sulphur)	0.4 cfs	4%	0.1 cfs	1%

Irrigation and non-irrigation season

Conditions during the irrigation and non-irrigation seasons were evaluated for temporal and spatial patterns and relations between variables.

Trends and percent differences

During the irrigation season, concentrations of most constituents and instantaneous discharge in the four waterways had a statistically significant ($p<0.05$) downward trend from 1997 through 2007* using the Seasonal Kendall trend test (table 6). Nitrate+nitrite concentrations had an upward trend in the four waterways during the irrigation season. Total Kjeldahl nitrogen had no trend except in Granger, which was downward.

Table 6. Seasonal Kendall trend test statistics

	Granger Drain			**Sulphur Creek Wasteway**			**Spring Creek Wasteway**			**Snipes Creek Wasteway**		
	Seasonal Kendall, S	z	p	Seasonal Kendall, S	z	p	Seasonal Kendall, S	z	p	Seasonal Kendall, S	z	p
Irrigation Season												
Total suspended solids	-157	-4.76	<0.001↓	-151	-4.58	<0.001↓	-195	-5.92	<0.001↓	-150	-4.62	<0.001↓
Total phosphorus	-156	-4.73	<0.001↓	-103	-3.11	0.002↓	-164	-4.97	<0.001↓	-87	-2.63	0.009↓
Nitrate+nitrite	100	3.02	0.002↑	85	2.56	0.010↑	74	2.23	0.026↑	69	2.08	0.038↑
Total Kjeldahl nitrogen	-86	-2.60	0.009↓	-42	-1.25	0.210	8	0.21	0.830	-4	-0.09	0.927
Fecal coliform	-99	-3.11	0.002↓	-74	-2.32	0.020↓	-85	-2.66	0.008↓	-64	-2.00	0.046↓
Discharge	-144	-4.43	<0.001↓	-79	-2.38	0.017↓	-130	-4.16	<0.001↓	-105	-3.41	<0.001↓
Non-irrigation season												
Total suspended solids	6	0.2	0.845	75	2.71	0.007↑	-5	-0.15	0.880	-150	-4.62	<0.001↓
Total phosphorus	-28	-1.13	0.257	101	3.90	<0.001↑	-8	-0.26	0.793	-87	-2.63	0.009↓
Nitrate+nitrite	55	2.25	0.024↑	90	3.44	<0.001↑	4	0.11	0.910	-75	-2.90	0.003↓
Total Kjeldahl nitrogen	-38	-1.54	0.123	55	2.1	0.036↑	32	1.17	0.242	-4	-0.09	0.926
Fecal coliform	-103	-3.99	<0.001↓	40	1.47	0.142	-127	-4.61	<0.001↓	-64	-2.00	0.046↓
Discharge	-26	-0.98	0.329	-58	-2.09	0.037↓	25	0.92	0.356	-4	-0.13	0.895

Arrows in 'p' column and cell color indicate trend direction: blue cells for upward and yellow cells for downward trends. Grey font indicates data did not exhibit a trend (p>0.05).

*Data for 2008 were not included because the data were not yet available when the trend test was conducted.

During the non-irrigation season, half of the analyses displayed no trend. Upward trends were observed in Sulphur for concentrations of total suspended solids, total phosphorus, nitrate+nitrite, and total Kjeldahl nitrogen and in Granger for nitrate+nitrite. Downward trends were observed in Granger for fecal coliform, in Sulphur for discharge, and in Snipes for total suspended solids, total phosphorus, nitrate+nitrite, and fecal coliform.

Between 1997 and 2008, median concentrations of most constituents decreased and all median loads decreased in the four waterways (table 7). The percent declines ranged from insignificant (less than the uncertainty in the data) to 96%.

If 2000 (the beginning of a more stable period) is used as a benchmark instead and compared against 2008, median concentrations generally increased but usually by smaller amounts than from 1997 to 2008, except for nitrate+nitrite. Median concentrations decreased significantly between 2000 and 2008 for total suspended solids in Sulphur and Spring, turbidity in Spring, and fecal coliform in Granger. Median discharge decreased significantly in all waterways except Snipes. Median loads of most constituents decreased significantly in Sulphur and Spring and increased in Granger and Snipes.

Table 7. Differences and percent differences in median concentrations and loads between 1997 and 2008 irrigation seasons and between 2000 and 2008 irrigation seasons.

Differences between 1997 and 2008							
Concentrations (median values, unless otherwise noted)							
	Turbidity (NTU), 90th percentile	Total suspended solids (mg/L)	Total phosphorus (mg/L)	Total Kjeldahl nitrogen (mg/L)	Nitrate + nitrite (mg/L)	Fecal coliform (col/100 mL), geo mean	Discharge (cfs)
Granger	-212	-173	-0.477	-0.59	0.13	-937	-11
Sulphur	-61	-198	-0.191	-0.27	-0.03	-1098	-171
Spring	-30	-107	-0.109	0.05	0.80	-461	-41
Snipes	-1	-27	0.01	0.04	-0.02	-28	-20
Loads (median values)							
		tons/ day	lb/day	lb/day	lb/day	million col/sec	
Granger	n/a	-39.5	-185	-225	-50	-18	n/a
Sulphur	n/a	-164	-415	-501	-2340	-117	n/a
Spring	n/a	-13.8	-38	-47	-159	-7	n/a
Snipes	n/a	-2.8	-11	-17	-76	-1	n/a

Differences between 2000 and 2008							
Concentrations (median values, unless otherwise noted)							
	Turbidity (NTU), 90th percentile	Total suspended solids (mg/L)	Total phosphorus (mg/L)	Total Kjeldahl nitrogen (mg/L)	Nitrate + nitrite (mg/L)	Fecal coliform (col/100 mL), geo mean	Discharge (cfs)
Granger	28	71	0.09	0.25	0.46	-299	-7
Sulphur	2	-26	0.0435	0.06	0.77	-55	-191
Spring	-5	-32	0.004	0.17	1.30	-23	-34
Snipes	7	-2.6	0.0265	0.09	0.21	15	-1
Loads (median values)							
		tons/ day	lb/day	lb/day	lb/day	million col/sec	
Granger	n/a	9.8	30	55	53	-5	n/a
Sulphur	n/a	-36.0	-45	-201	-879	-17	n/a
Spring	n/a	-4.7	-24	-41	-26	-2	n/a
Snipes	n/a	0.1	2	8	19	-0.2	n/a

Percent differences between 1997 and 2008							
Concentrations (median values, unless otherwise noted)							
	Turbidity, 90th percentile	Total suspended solids	Total phosphorus	Total Kjeldahl nitrogen	Nitrate + nitrite	Fecal coliform, geo mean	Discharge
Granger	-74	-49	-58	-50	5	-66	-17
Sulphur	-75	-90	-54	-42	-1	-73	-52
Spring	-60	-91	-51	13	66	-69	-75
Snipes	-5	-65	6	15	-3	-27	-40
Loads (median values)							
Granger	n/a	-61	-65	-58	-6	-70	n/a
Sulphur	n/a	-96	-71	-59	-56	-85	n/a
Spring	n/a	-97	-85	-62	-51	-89	n/a
Snipes	n/a	-70	-46	-27	-55	-77	n/a

Percent differences between 2000 and 2008							
Concentrations (median values, unless otherwise noted)							
	Turbidity, 90th percentile	Total suspended solids	Total phosphorus	Total Kjeldahl nitrogen	Nitrate + nitrite	Fecal coliform, geo mean	Discharge
Granger	63	65	36	70	20	-38	-12
Sulphur	13	-53	36	20	52	-12	-54
Spring	-20	-75	4	65	187	-10	-71
Snipes	46	-15	39	40	64	24	-2
Loads (median values)							
Granger	n/a	63	45	51	7	-39	n/a
Sulphur	n/a	-83	-21	-36	-33	-45	n/a
Spring	n/a	-92	-78	-60	-15	-70	n/a
Snipes	n/a	9	22	23	44	-35	n/a

Negative values in yellow cells indicate a decrease between years; positive values in blue cells indicate an increase. Grey font indicates insignificant differences -- relative percent differences (not shown) were less than the uncertainty in the field replicate samples. When differences between concentrations were insignificant, the differences between the corresponding loads were also considered insignificant.

Irrigation season by year, by site

Concentrations

Evaluating median values by year, Snipes had the lowest concentrations of most parameters and lowest instantaneous discharge (figure 5). In most years, Granger had the highest concentrations or values of total suspended solids, turbidity, fecal coliform, and total phosphorus. Fecal coliform concentrations were the most variable. Nitrate+ nitrite concentrations were higher in Sulphur and Granger than in Spring and Snipes in every year. Instantaneous discharge was higher in Sulphur than the other waterways: it had the largest drainage area and received more operational spill water than Spring or Snipes. The patterns in changes in total dissolved solids and nitrate+nitrite concentrations between years were often similar, suggesting nitrate+nitrite was behaving somewhat conservatively.

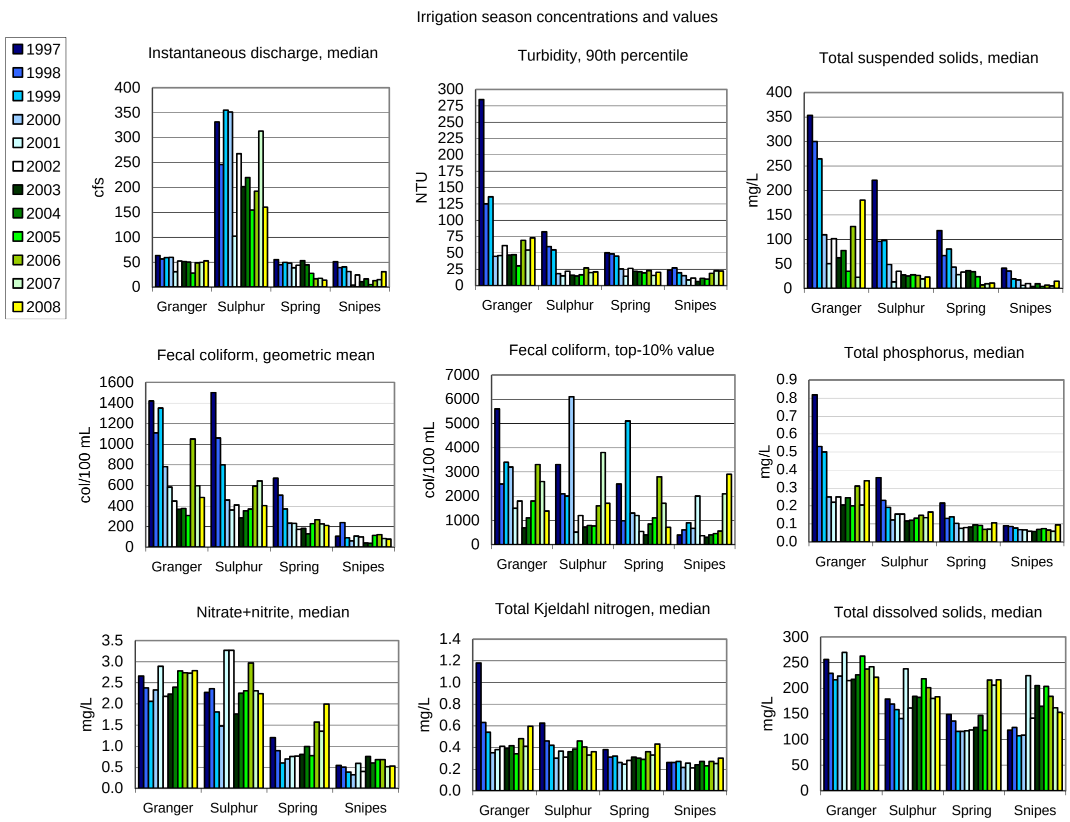


Figure 5. Median and other calculated concentrations and values by year, Granger, Sulphur, Spring, and Snipes, 1997 to 2008 irrigation seasons.

To determine whether the often high constituent concentrations in 1997 to 1999 were atypical, historical data from the Environmental Protection Agency's Legacy Data Center, from 1974 to 1980 for Spring and Snipes, and 1974 to 1981 for Sulphur and Granger were compared to recent data (figure 6). Only constituents with comparable numbers of years of data were evaluated; turbidity was not evaluated because of its similarity to total suspended solids. The historical sites were at the same location as the RSBOJC sites for Spring and

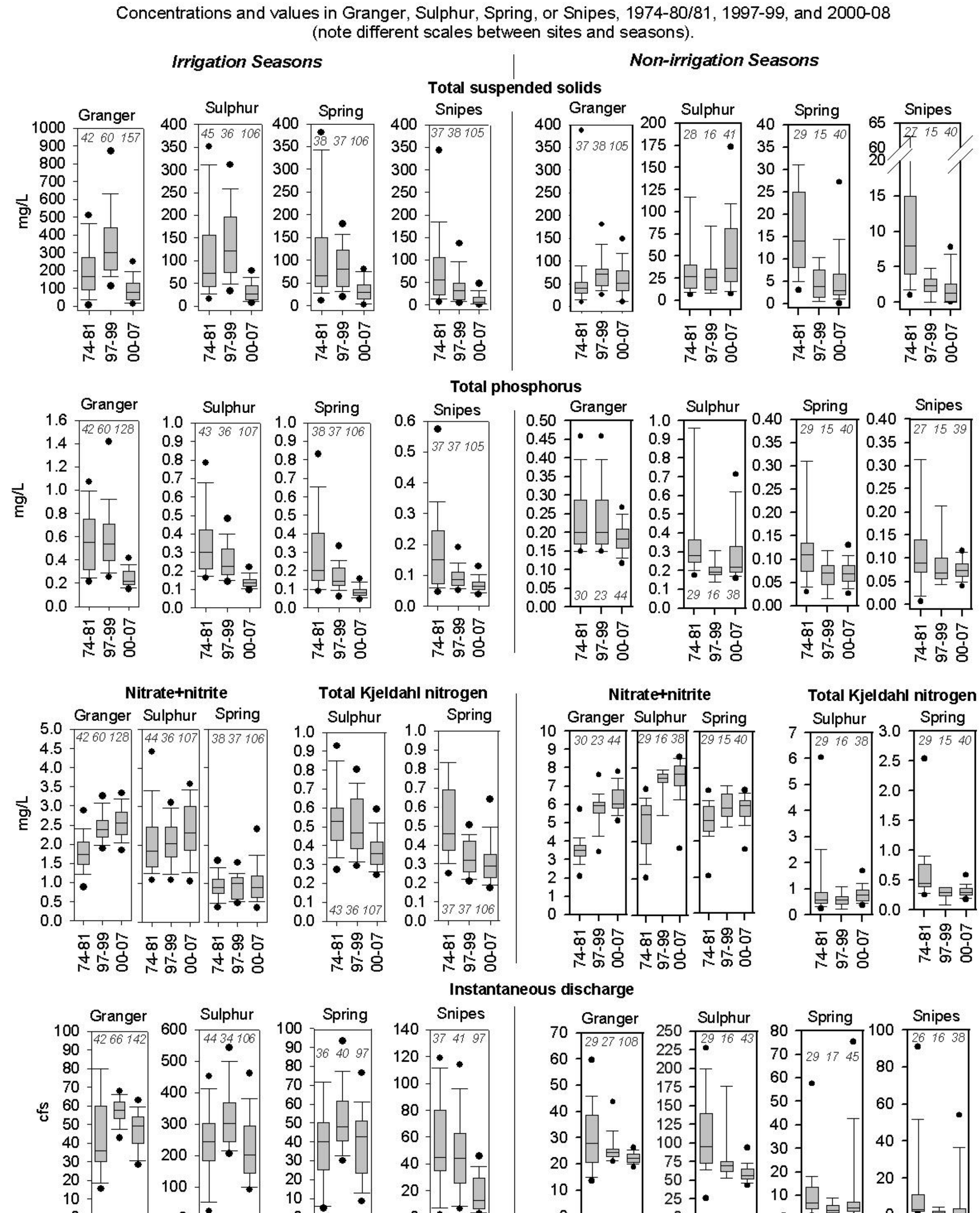


Figure 6. Concentrations and values, Granger, Sulphur, Spring, and Snipes, 1974 to 1980/81 (EPA data), 1997 to 1999 and 2000 to 2007 (RSBOJC data).

Snipes, and within 0.1 and 0.5 miles of current Sulphur and Granger sites with no sub-drains between the past and current sites.

During the irrigation seasons, concentrations of most parameters at most sites from 1997 to 1999 were comparable to 1974 to 1981. Exceptions include: compared to 1974 to 1981, concentrations from 1997 to 1999 of total suspended solids in Granger were greater, concentrations of total suspended solids and total phosphorus in Snipes were less, total Kjeldahl nitrogen in Spring was less, and discharge in Granger was greater. Similarly, concentrations of most parameters and discharge values at most sites from 2000 to 2007 were less than during 1997 to 1999, except a few conditions which were comparable between sets of years (e.g., total Kjeldahl nitrogen concentrations and discharge values in Spring, and nitrate+nitrate concentrations in Spring and Sulphur).

During the non-irrigation seasons, most concentrations in 1974 to 1981 were greater than or comparable to the other sets of years. Discharge was greater in 1974 to 1981 at all four sites than other sets of years; however, the accuracy of the discharge values from the legacy database is unknown since most of the discharge values were estimated. Nitrate+nitrite concentrations in Granger and Sulphur were less in 1974 to 1981 than later years.

Loads

Irrigation season median loads varied as much as an order of magnitude between waterways and between years (figure 7). For example, median loads of total suspended solids in Sulphur decreased from 171 tons per day in 1997 to 7 tons per day in 2008, while

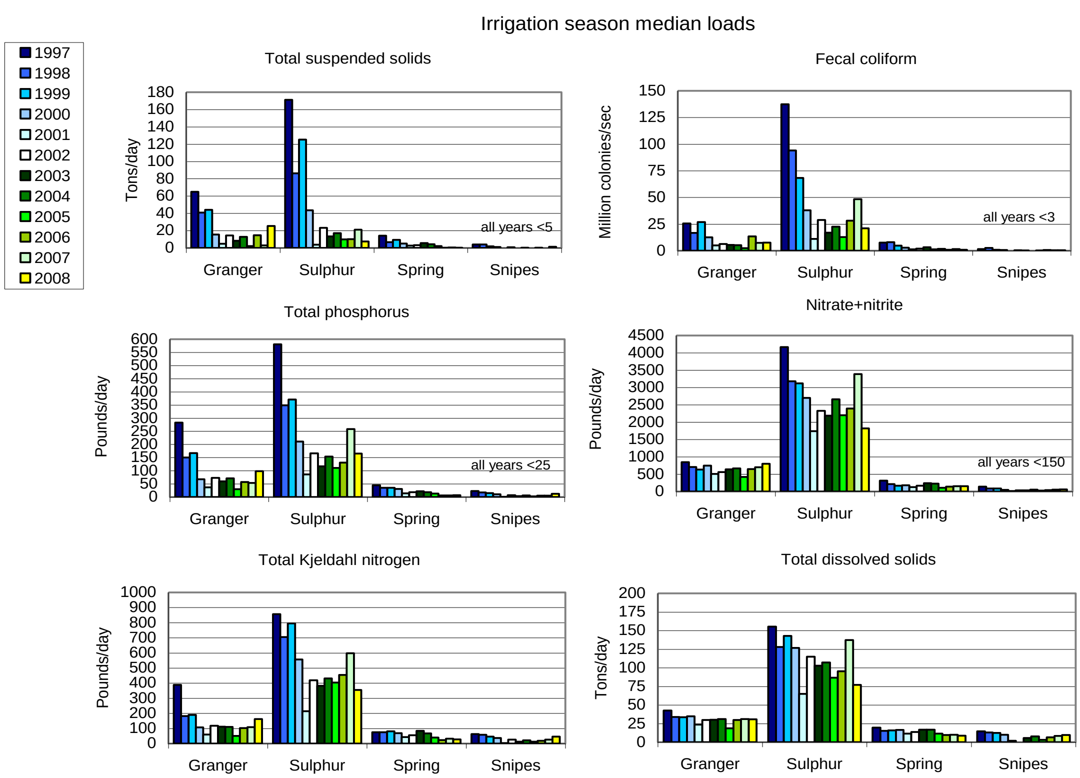


Figure 7. Median loads by year, Granger, Sulphur, Spring, and Snipes, 1997 to 2008 irrigation seasons.

in Snipes median loads decreased from 4.1 to 1.2 tons per day. Median nitrate loads ranged from 4,200 to 1,700 pounds per day in Sulphur and 140 to 10 pounds per day in Snipes. (Because of the difficulty in displaying such wide ranges in conditions, a table of the median values in these charts is included in the appendix.) Loads were often highest in Sulphur followed by, in descending order, Granger, Spring, and Snipes; the same descending order as discharge values.

Drainage area input and outputs

The estimated seasonal load of total suspended solids delivered by the canals to each drainage area (the input) compared to the seasonal load leaving each drainage area (the output) varied between the two years evaluated and between drainages (table 8). The years of 2000 and 2004 were evaluated because those were the only two years with data for canals sites near their entry to the drainages during the more stable period of 2000 to 2008. Annual mean discharge in the Yakima River at Kiona was slightly above-average in 2000 and well-below average (25th percentile) in 2004. In Granger, 63 to 90% of the output was contributed by the inputs. In Sulphur, 66 to 75% of the output was contributed by the input. In Spring/Snipes, the input exceeded the output in both years.

Table 8. Estimated seasonal load of total suspended solids, input from canals and output from Granger, Sulphur, and Spring + Snipes, 2000 and 2004 irrigation seasons.

	2000 irrigation season				2004 irrigation season			
Drainage	*TSS Input (tons)*	*TSS Output (tons)*	*Difference (tons)*	*% of output contributed by input*	*TSS Input (tons)*	*TSS Output (tons)*	*Difference (tons)*	*% of output contributed by input*
Granger	2,640	2,920	280	90	1630	2600	974	63
Sulphur	6,060	8,060	1,990	75	3590	5420	1830	66
Spring + Snipes	1,970	1,880	-85	105	1490	1093	-394	136

Assumptions on which the above estimates were based included: an average 3 ac-ft per acre was applied to the irrigated portions of these drainage areas, the accuracy of which is unknown; the total suspended solids concentration on the sampled day represented the two week period between sampling, which is often untrue in highly variable systems such as these; and all of the total suspended solids load measured in the canal was delivered to farms, when, in fact, some of the load was likely deposited before reaching the farms.

Yields

Granger, the only drain not receiving spill water from canals, had the lowest discharge yield (less than 1 ac-ft per acre per 200-day irrigation season) except in the drought years of 2001 and 2005 when Snipes was lower (figure 8). Snipes receives operational spill from the Roza Canal; the amount spilled was minimal in drought years. Sulphur had the largest and most variable discharge yields, from less than 1 ac-ft/ac/200 days in the drought of 2001 to 2.8 ac-ft/ac/200 days in 1999 and 2000. In 2004, the average estimated amount delivered to farms was 2.6 ac-ft per acre for Roza and 3.1 ac-ft per acre for Sunnyside (personal communication, Don Schramm, Sunnyside Division, January 2009, and Wayne Sonnichsen, Roza Irrigation District, December 2008). Historically, in 1944 in the central area of the Sunnyside Division, the water application rate was 4.4 ac-ft/ac and yield was 2.2 ac-ft/ac/year (Poe, 1961). In 1975, crop consumptive use accounted for only 42-46% of

diverted water in the Sunnyside and Roza Divisions (CH2M Hill, 1975). The efficiency of the delivery systems has since improved substantially through installation of automatic drop structures, pressurizing laterals, and other structural improvements.

The highest yields of total suspended solids and total phosphorus were from 1997-99 in Sulphur and Granger while the lowest were in Spring and Snipes. Extrapolating the 2000-2008 range of median total suspended solids yields of 0.2 to 2.5 lb/ac/day in Sulphur to the entire irrigation season results in a rough estimate of 40 to 500 lb/ac per irrigation season – substantially less than the 1.9 tons/ac (3,800 lb/ac) reported for the 1976 irrigation season in Sulphur (Boucher and Fretwell, 1982). Similarly, extrapolating nitrate+nitrite and total phosphorus median yields resulted in rough estimates of 6 to 14 lb/ac nitrate+nitrite and 0.4 to 1.4 lb/ac total phosphorus. During the 1976 irrigation season, yields were about 14 lb/ac

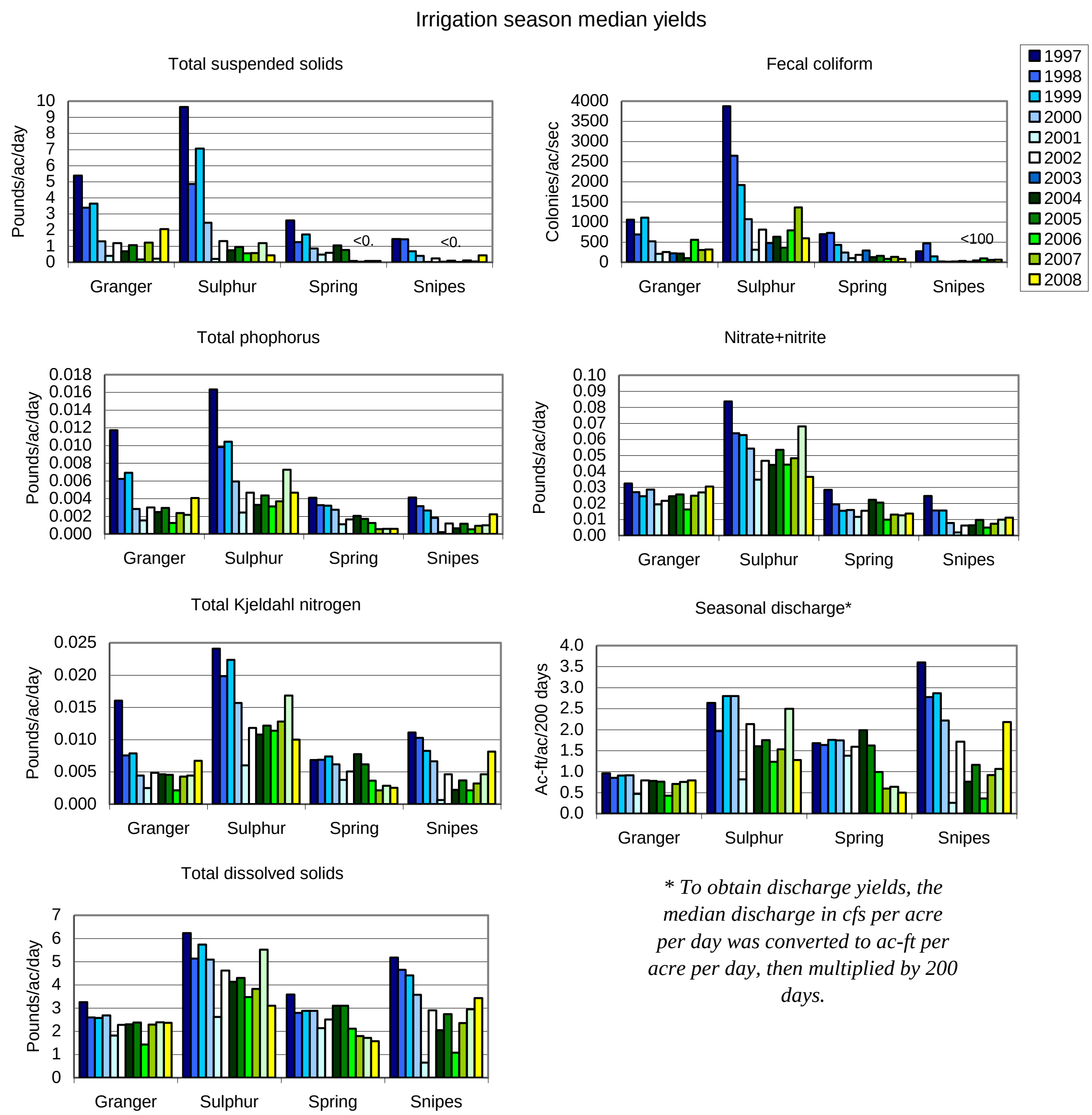


Figure 8. Median yields by year, Granger, Sulphur, Spring, and Snipes, 1997 to 2008 irrigation seasons.

nitrate+nitrite and 2.4 lb/ac total phosphorus (Boucher and Fretwell, 1982); in 1976, annual mean discharge in the Yakima River at Kiona was in top the 10% of discharge values from 1934 to 2007, indicative of an abundant irrigation water supply.

Comparing yields of total suspended solids to soil loss tolerances, most yields from these four waterways since 2000 were less than 0.25 tons per acre per year – far less than typical soil loss tolerances. Major soil types (those accounting for at least four percent of the irrigated acres) in these four drainage areas had soil loss tolerances (USDA, 1985) of 5 tons per acre (9 soil types out of 19), 2-3 tons per acre (5 of 19) and 1 ton per acre (5 of 19).

Non-irrigation season

Concentrations

Unlike the irrigation seasons, concentrations and values during the non-irrigation seasons were variable between years with no apparent patterns consistent between the four waterways (figure 9). In 2006 and 2007, median total phosphorus and fecal coliform concentrations increased significantly and substantially in Sulphur compared to previous years. The highest median total Kjeldahl nitrogen concentrations were usually in Sulphur. Nitrate+nitrite concentrations were lowest in Snipes and comparable in Granger and Spring. Total dissolved solids concentrations were relatively uniform except in Snipes.

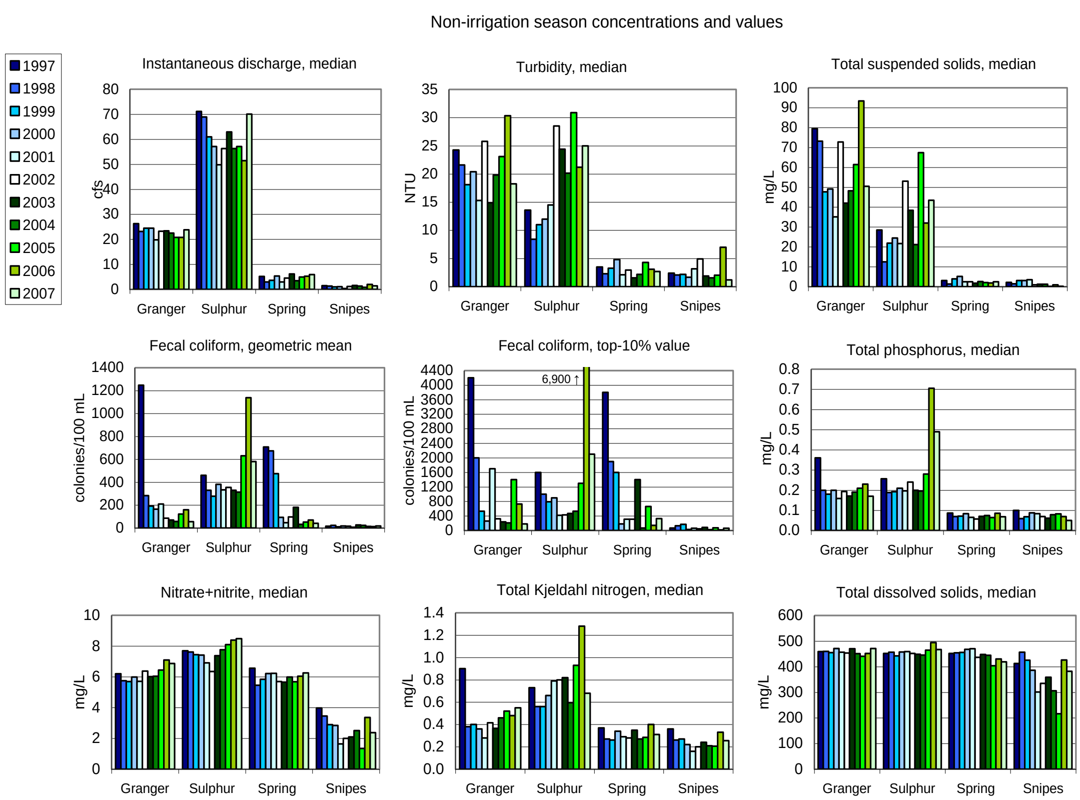


Figure 9. Median concentrations and values by year, Granger, Sulphur, Spring, and Snipes, 1997 to 2007 non-irrigation seasons.

The ratio of non-irrigation to irrigation season instantaneous discharge may be used as a rough indicator of the relative importance of groundwater and operational canal spills to the waterways. Median ratios from 1997 to 2007 were 0.45, 0.26, 0.10, and 0.08 in Granger, Sulphur, Spring, and Snipes, respectively. Granger is the only waterway which does not receive significant canal spill water. A sub-drain of Granger was found to contain 41% groundwater in the 2004 irrigation season based on a mass balance and mixing analysis approach using discharge, specific conductance and upward hydraulic gradients (Domagalski *et al*, 2008), suggesting the rough estimate using simple ratios was reasonable.

Loads

As during the irrigation seasons, the highest to lowest non-irrigation season median loads (figure 10) generally followed the same order as the drainage area size. Unlike the irrigation seasons, median loads did not typically decrease over time. Variability in loads between years was a function of variability in discharge and concentrations. For example, total suspended solids concentrations and instantaneous discharge in Sulphur were highly variable between years, resulting in large differences in load. Median total dissolved solids concentrations were stable between years in Sulphur, yet median loads in Sulphur varied – solely due to varying discharge.

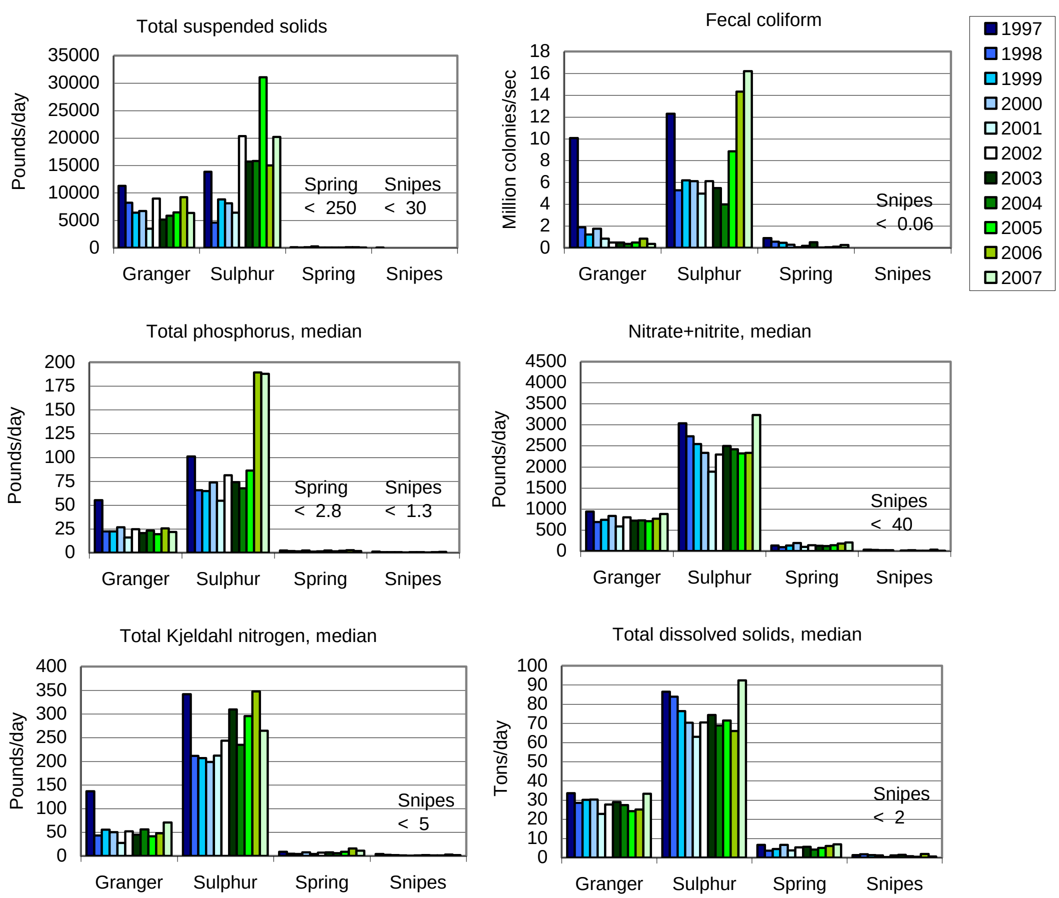


Figure 10. Median loads by year, Granger, Sulphur, Spring, and Snipes, 1997 to 2007 non-irrigation seasons.

Yields

Unlike the irrigation season, median yields did not typically decrease with time. But like the irrigation season, median yields of all constituents from Spring and Snipes were less than from Granger or Sulphur (figure 11) – for total suspended solids by 1-3 orders of magnitude and for total dissolved solids by about 0.1 to 0.5x. Sulphur had the highest yields, except in three years when Granger had higher yields (of total suspended solids in 1999 and 2000 and of fecal coliform in 1997). Total phosphorus yields in Sulphur increased in 2006-07 by roughly 2.5x compared to 2000-05.

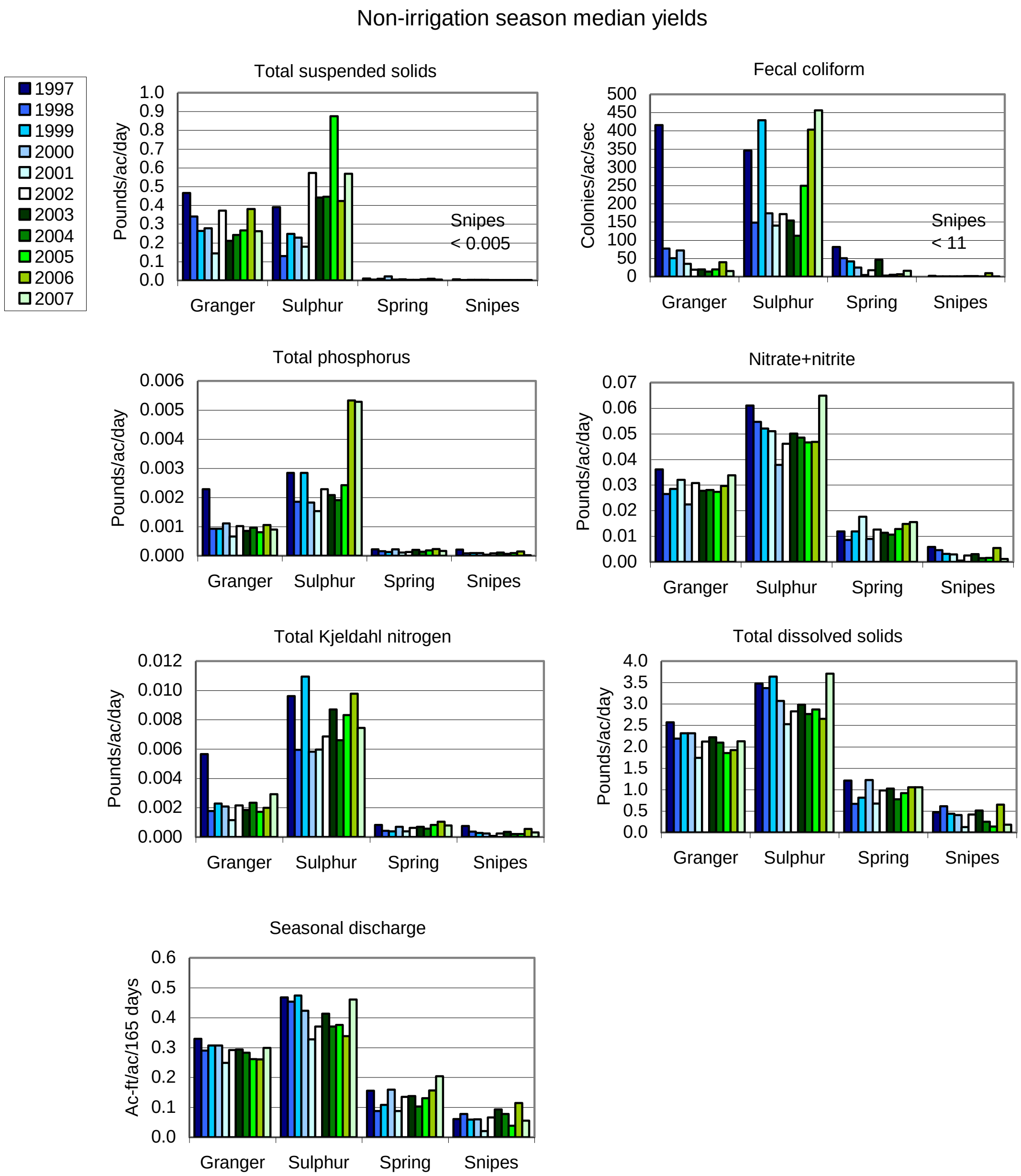


Figure 11. Median yields by year, Granger, Sulphur, Spring, and Snipes, 1997 to 2007 non-irrigation seasons.

Irrigation vs. non-irrigation seasons

Concentrations

When considering all years of data by season, in Granger, Spring, and Snipes, irrigation season concentrations were significantly higher than non-irrigation season concentrations of total suspended solids, turbidity, fecal coliform (except Spring), and total phosphorus (except Snipes), while total Kjeldahl nitrogen concentrations were comparable between seasons (figure 12). In Sulphur, irrigation season concentrations of total phosphorus and total Kjeldahl nitrogen were lower than non-irrigation season concentrations, while irrigation and non-irrigation season turbidity values and concentrations of total suspended solids and fecal coliform were comparable. In all four waterways, nitrate+nitrite concentrations were significantly higher during non-irrigation seasons than irrigation seasons.

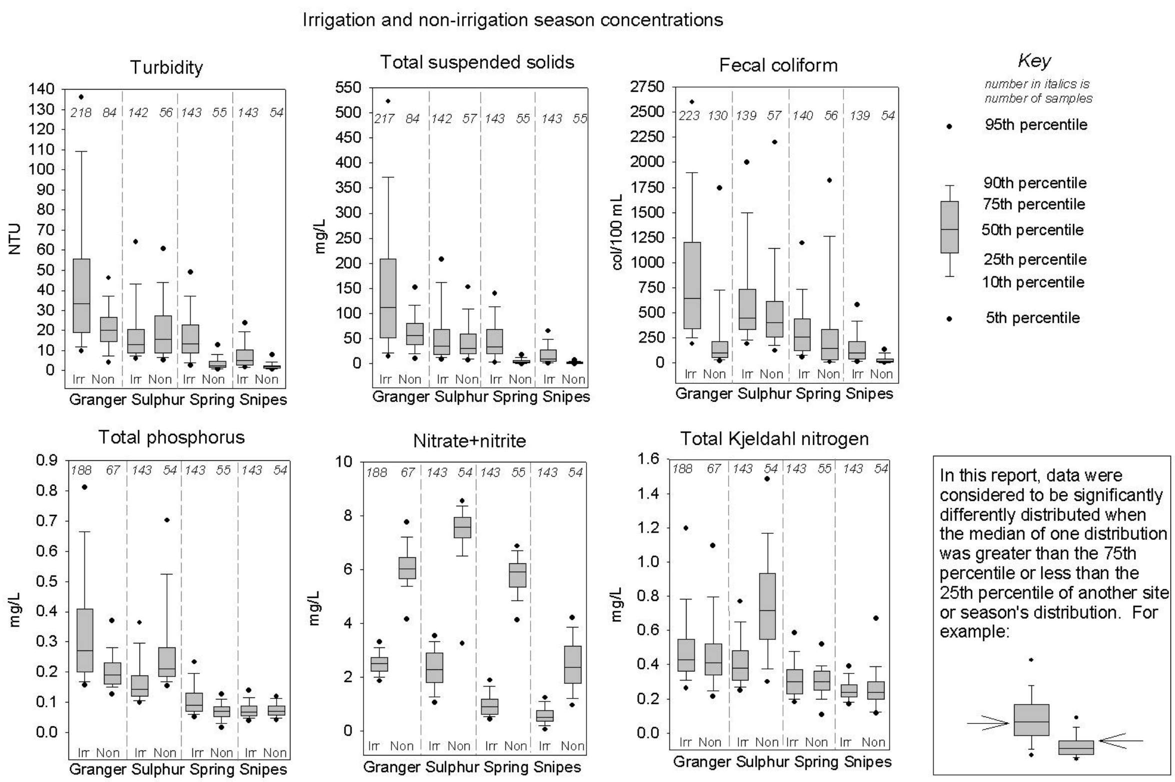
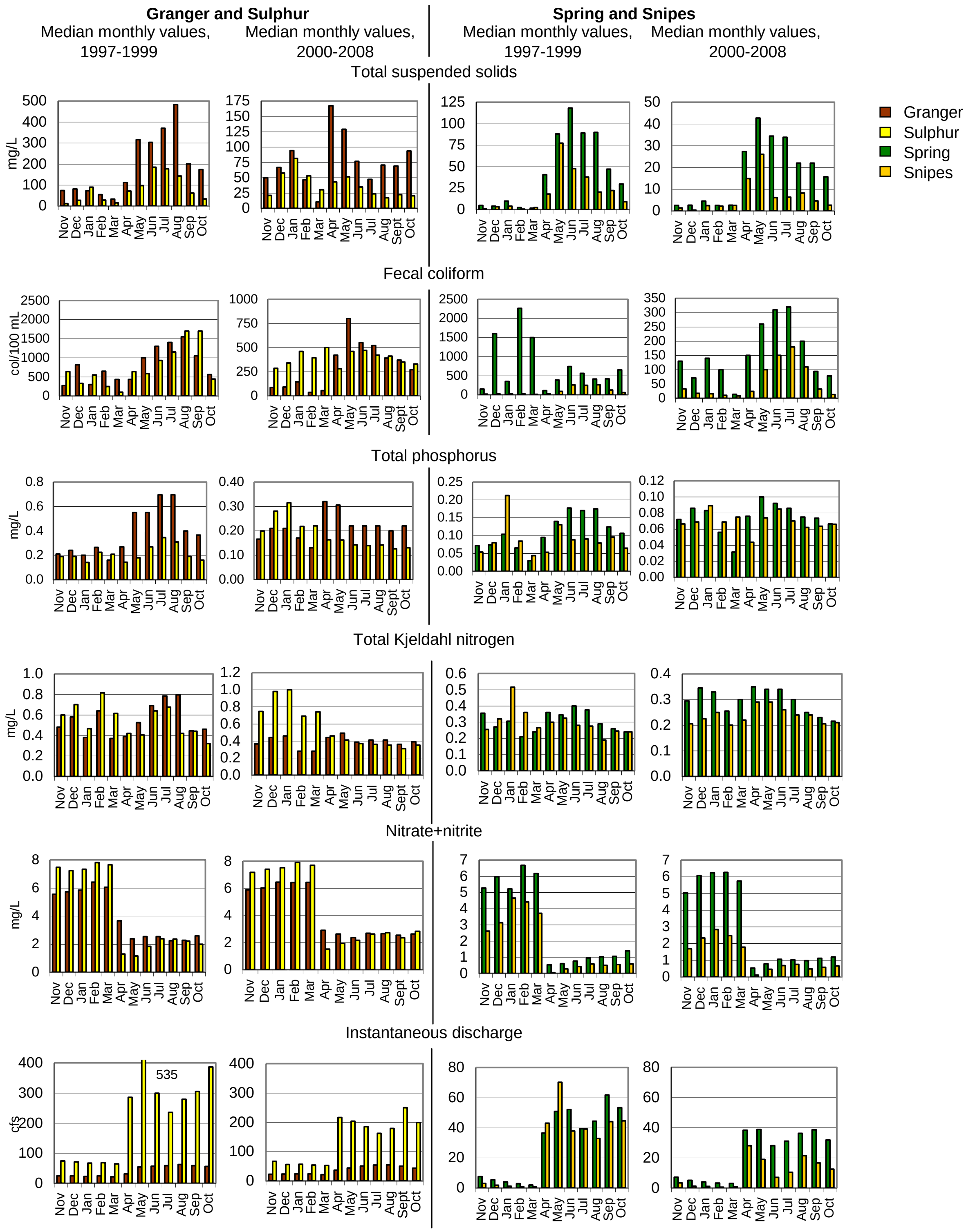


Figure 12. Concentrations and values, Granger, Sulphur, Spring, and Snipes, 1997 to 2008 irrigation and non-irrigation seasons.

Monthly values

Because of the substantial decline in irrigation season concentrations from 1997 to 2000, monthly median concentrations were considered separately for 1997 to 1999 and 2000 to 2008 in each waterway (figure 13). Monthly patterns of median nitrate+nitrite concentrations and discharge values were similar between sets of years. Patterns of total suspended solids, fecal coliform, total phosphorus, and total Kjeldahl nitrogen changed between sets of years.



Note different scales between sites and often between groups of years.

Figure 13. Median concentrations and values by month, Granger, Sulphur, Spring, and Snipes, 1997 to 1999 and 2000 to 2008.

Total suspended solids median concentrations in 1997 to 1999 were often higher during irrigation season months than non-irrigation season months in all four drains. From 2000 to 2008, this remained the case in Spring and Snipes. In Granger, however, concentrations in November through February became comparable to June through September; in Sulphur, concentrations in December through February became higher than June through September.

The pattern of fecal coliform median concentrations changed the most in Sulphur and Spring. In Sulphur, concentrations peaked in August through September in 1997 to 1999 but became nearly constant from January through June in 2000 to 2008. In Spring, the highest concentrations occurred during non-irrigation season months in 1997 to 1999 but during the irrigation season months in 2000 to 2008.

Total phosphorus median concentrations in Granger became comparable during December-January and June through August in 2000 to 2008 as a result of decreased irrigation season and increased non-irrigation season concentrations. In Sulphur, the highest concentrations occurred in July-August in 1997 to 1999 but in December-January in 2000 to 2008. In Spring, in 2000 to 2008, concentrations in November through January became similar to June through September. In Snipes, a January peak in 1997 to 1999 changed to similar concentrations almost year-round in 2000 to 2008.

Total Kjeldahl nitrogen concentrations in Granger changed from being variable year-round in 1997 to 1999 to becoming nearly constant year-round in 2000 to 2008. In Sulphur, they changed from being variable year-round to the non-irrigation season months having higher concentrations than irrigation season months. In Snipes a peak in January 1997 to 1999 changed to being similar year-round (except dip in April). In Spring the patterns were similar between sets of years.

Granger and Sulphur sub-drains

The influence of operational spills on Sulphur, Spring, and Snipes limits comparisons of these waterways to Granger, which does not receive operational spill water. However, sub-drains in Sulphur and Granger, none of which receive substantial spill water, were sampled from 1999 to 2005, allowing for direct comparisons. A site downstream of Sunnyside was not included in the comparison of sub-basins, to avoid possible urban influences.

During the irrigation season, turbidity values and total suspended solids, fecal coliform, and total Kjeldahl nitrogen concentrations were comparable in Granger and Sulphur sub-basins (figure 14). Total phosphorus concentrations were lower in Sulphur than Granger sub-drains; thus, the lower concentrations observed near the mouth of Sulphur were not solely due to the diluting influence of spill water. Nitrate+nitrite concentrations were higher in Sulphur than Granger sub-drains, unlike the mouths which were comparable, suggesting a diluting influence from operational spill. Comparing each mouth to its sub-drains, concentrations of all constituents at the mouth of Granger were comparable to concentrations in its sub-drains. In Sulphur, turbidity values and concentrations of total suspended solids, total phosphorus, and nitrate+nitrite were significantly lower at the mouth than in its sub-drains, again suggesting a diluting influence from operational spill.

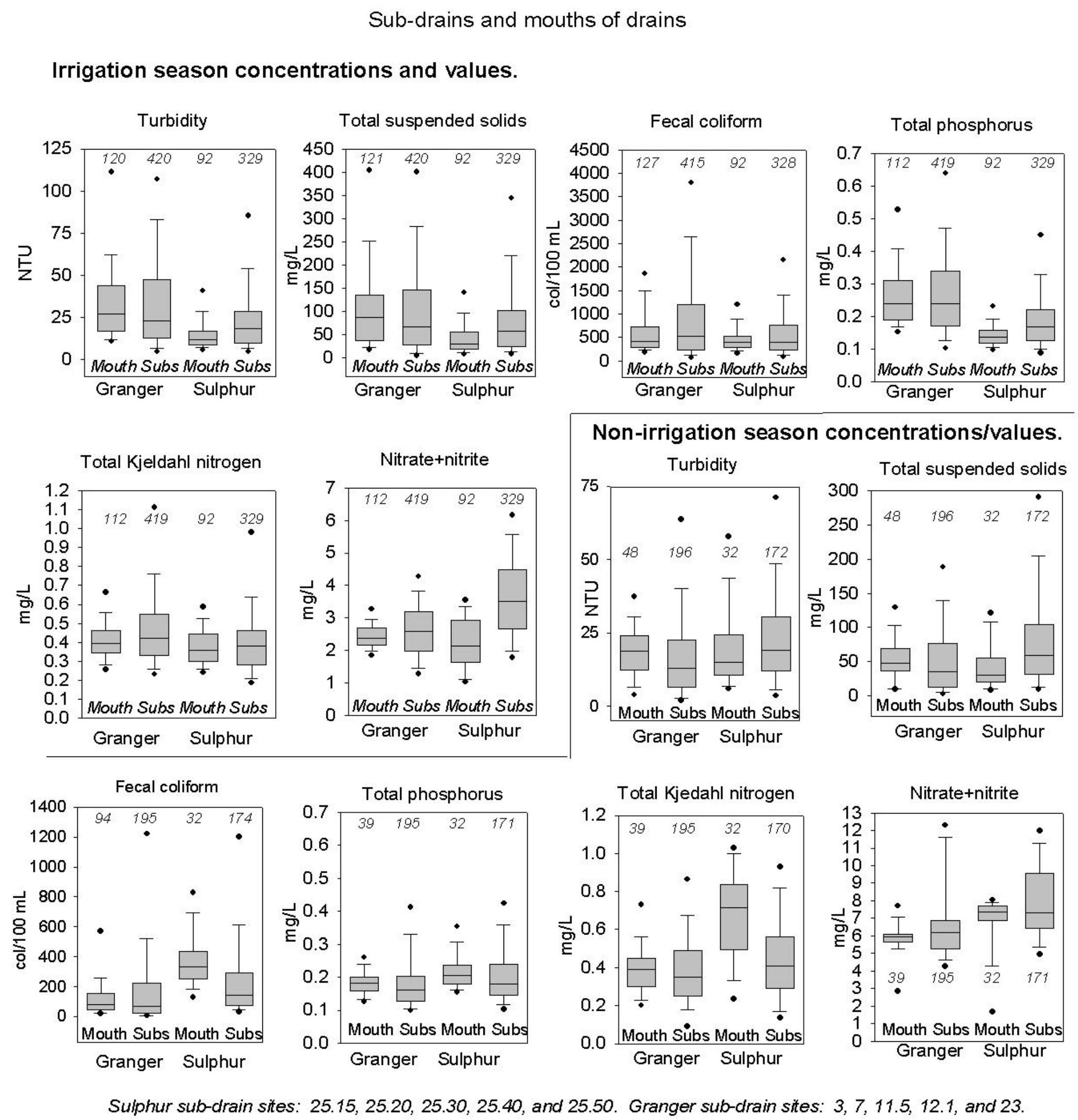


Figure 14. Concentrations and values, Granger and Sulphur mouths and sub-drains, 1999 to 2005 irrigation seasons.

During the non-irrigation season, when no spills occur, several concentrations/values at the mouths were comparable to the sub-drains. Nitrate+nitrite concentrations in the Granger sub-drains, however, were higher than at the mouth. In the Sulphur sub-drains, fecal coliform and total Kjeldahl nitrogen concentrations were lower and total suspended solids were higher than the mouth.

Variability between sub-drains within either drainage area tended to be high (figure 15). For example, within Sulphur, site 25.10 often had 2-3x higher fecal coliform, total phosphorus, and total Kjeldahl nitrogen median concentrations than the other Sulphur sites, especially during the non-irrigation season, while site 25.3 had elevated nitrate+nitrite concentrations. Within Granger, median nitrate+nitrite concentrations at site 23 were roughly double other Granger sites.

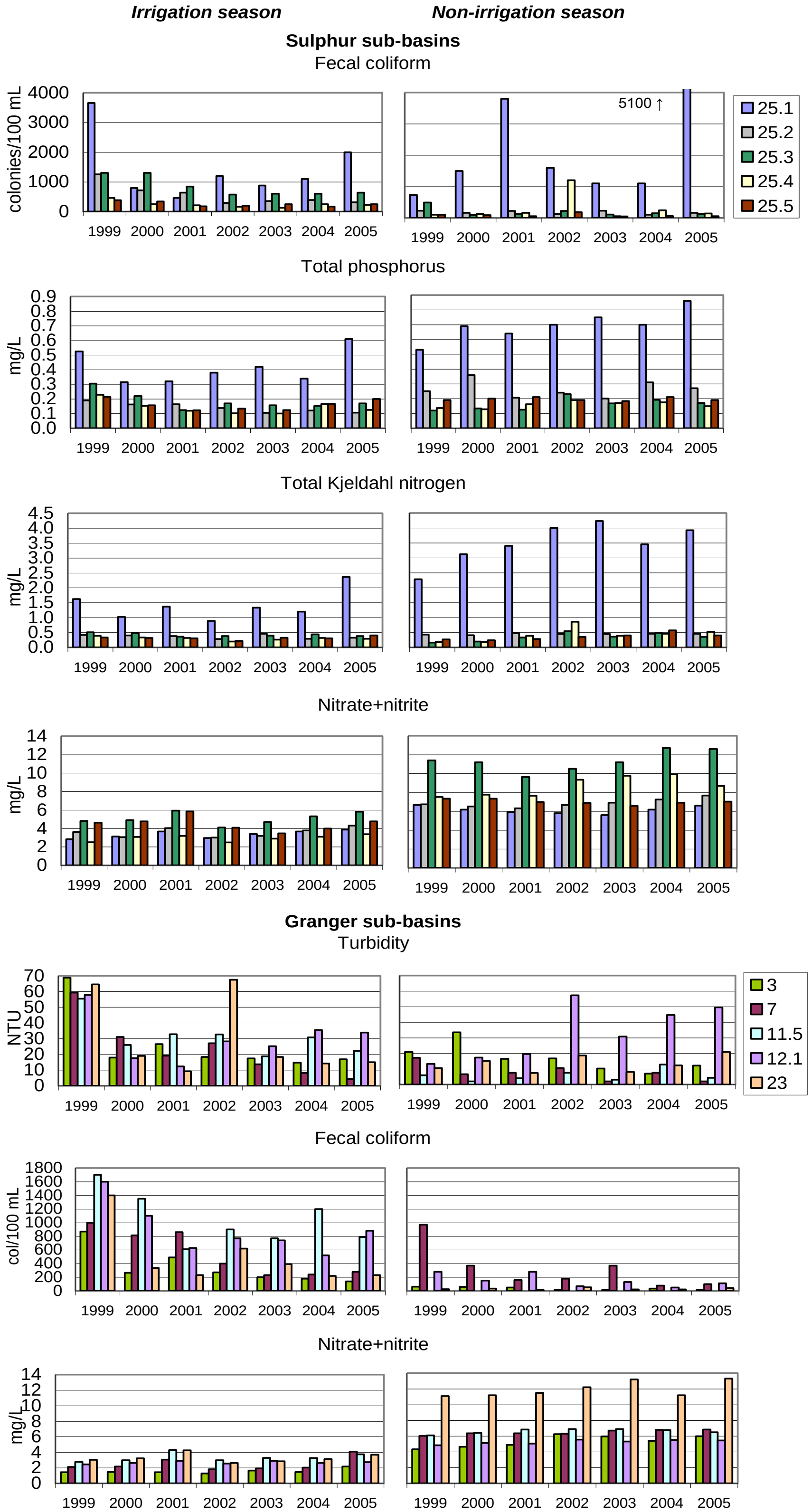


Figure 15. Median concentrations, Sulphur and Granger individual sub-drains, select parameters, 1999 to 2005 irrigation and non-irrigation seasons.

Sulphur upstream and downstream of urban area.

Because of the unusually high concentrations of fecal coliform, total phosphorus, and total Kjeldahl nitrogen at site 25.10, downstream of the City of Sunnyside, additional data were analyzed at a site on the same drain as 25.10 but upstream of most of the Sunnyside urban area. Between the upstream and downstream sites, median concentrations and yields of these three constituents often increased substantially, especially during the non-irrigation season (figures 16 and 18).

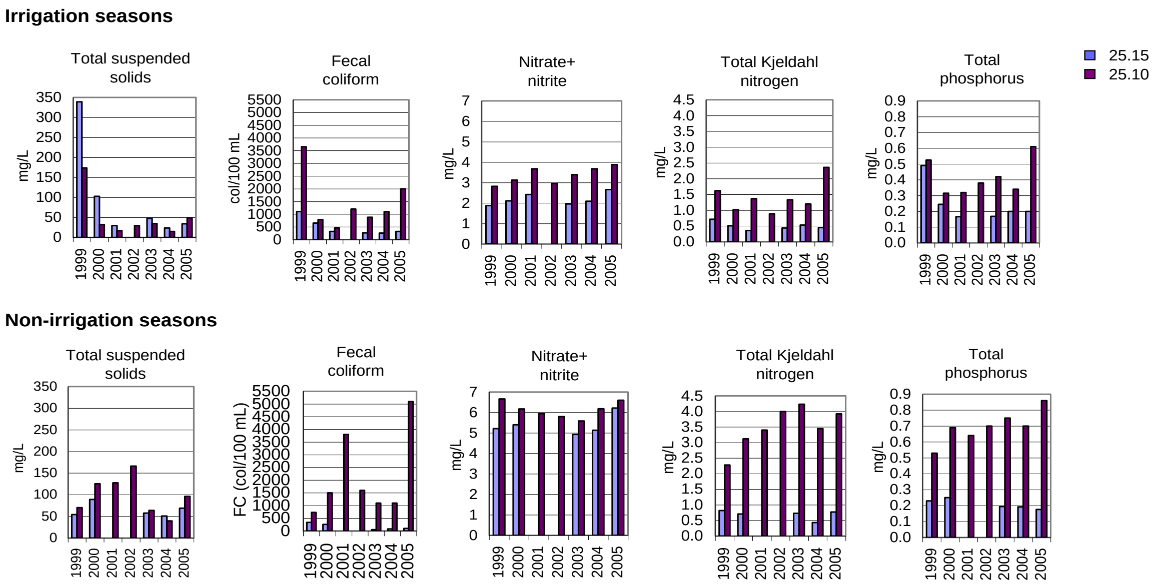


Figure 16. Concentrations, JD 33.4 upstream (site 25.15) and downstream (site 25.10) of Sunnyside, 1999 to 2005 irrigation and non-irrigation seasons.

RSBOJC discontinued sampling sub-basins in 2005 but recent data from the mouth of Sulphur suggest the pattern found in the older data may be continuing. Elevated nutrient and fecal coliform concentrations which did not coincide with elevated total suspended solids concentrations occurred intermittently in recent non-irrigation seasons (figure 17).

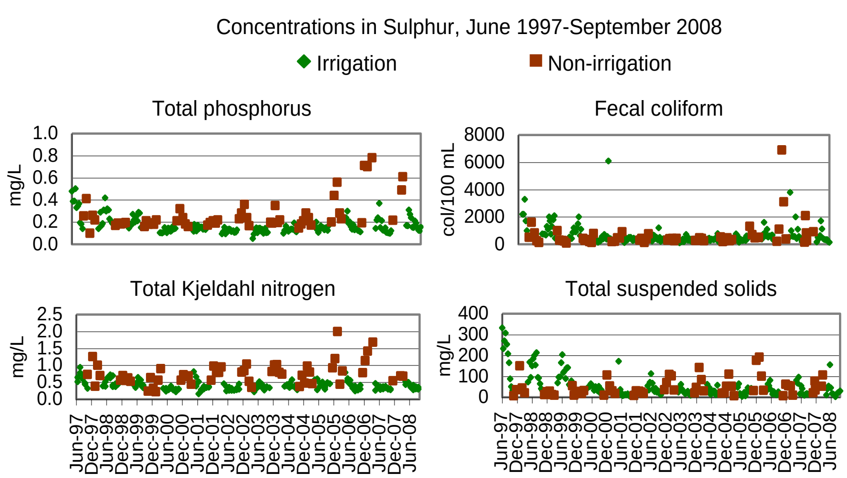


Figure 17. Concentrations, select constituents, Sulphur Creek Wasteway, June 1997 to September 2008.

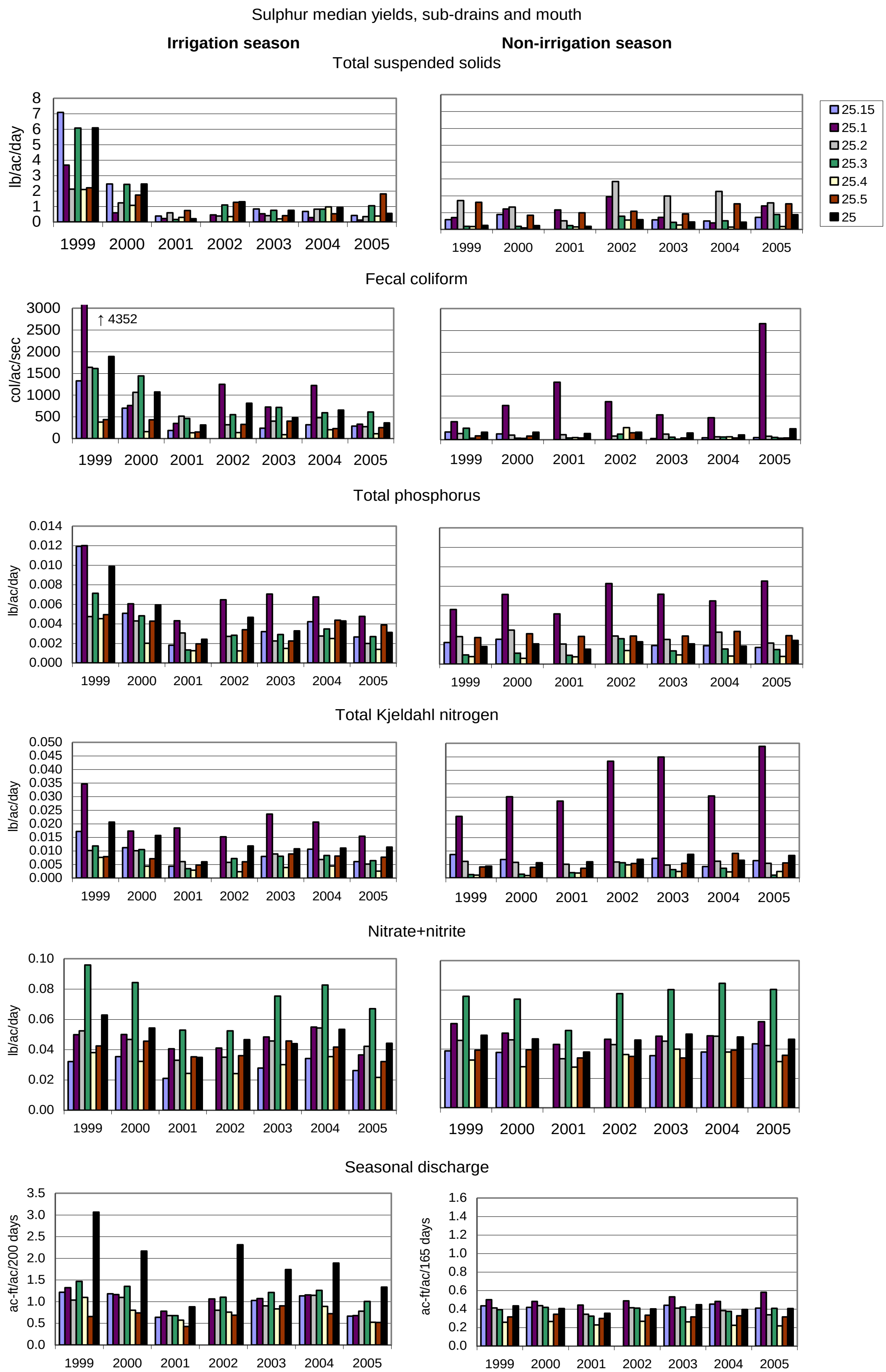


Figure 18. Median yields by year, Sulphur individual sub-drains and mouth, 1999 to 2005 irrigation and non-irrigation seasons.

Granger phosphorus synoptic

Total phosphorus and orthophosphate concentrations varied widely in a synoptic sampling of the Granger drainage area on March 14, 2005. Within a roughly three square mile area, total phosphorus ranged from 57 to 610 ug/L and orthophosphate ranged from 30 to 124 ug/L (figure 19). Irrigation had not yet begun in mid-March, and no significant rainfall occurred for more than a week before the sampling, thus the primary source of the water in Granger was groundwater. However, because biological and chemical processes often occur as groundwater infiltrates the drain, the orthophosphate concentrations in the drain were likely not the same as groundwater concentrations.

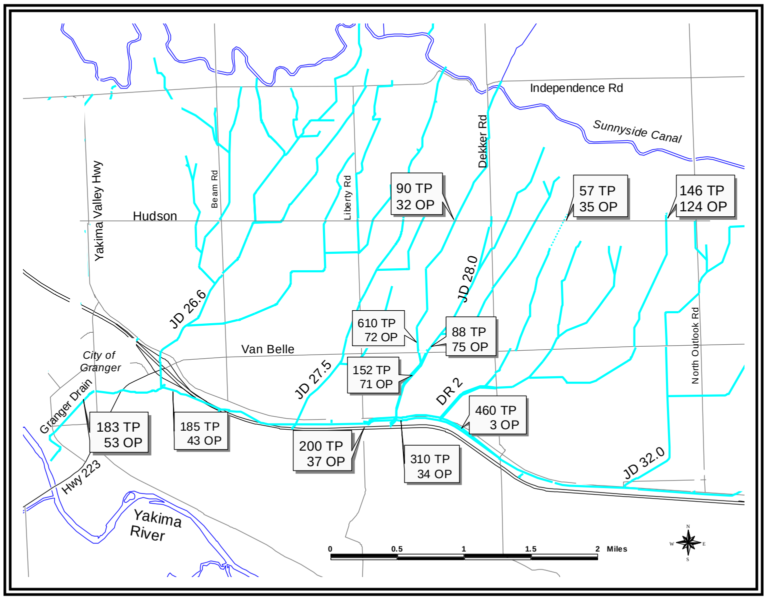


Figure 19. Synoptic sampling of total phosphorus and orthophosphate in Granger drainage, March 14, 2005.

Loads

In 1976-77, only three percent of the total yearly load of total suspended solids in Sulphur Creek Wasteway was from the November to March period (Boucher and Fretwell, 1982). For this report, the relative importance of the irrigation and non-irrigation seasons was estimated by comparing the proportion of the median load during the irrigation season and the median load during the non-irrigation season relative to their sum in 1997 and 2007. As in 1976-77, in 1997 the median load of total suspended solids during the non-irrigation season was a small fraction of the sum in all four waterways (figure 20). However, in 2007, in Sulphur and Granger, the median load during the non-irrigation season was roughly 0.3 and 0.5 of the summed loads and the median total phosphorus load during the non-irrigation season was roughly 0.4 and 0.3 of the summed loads. The increased proportion of non-irrigation season loads was a result of substantially decreased irrigation season loads, except for total phosphorus in Sulphur, which was a result of decreased irrigation season loads and increased non-irrigation season loads.

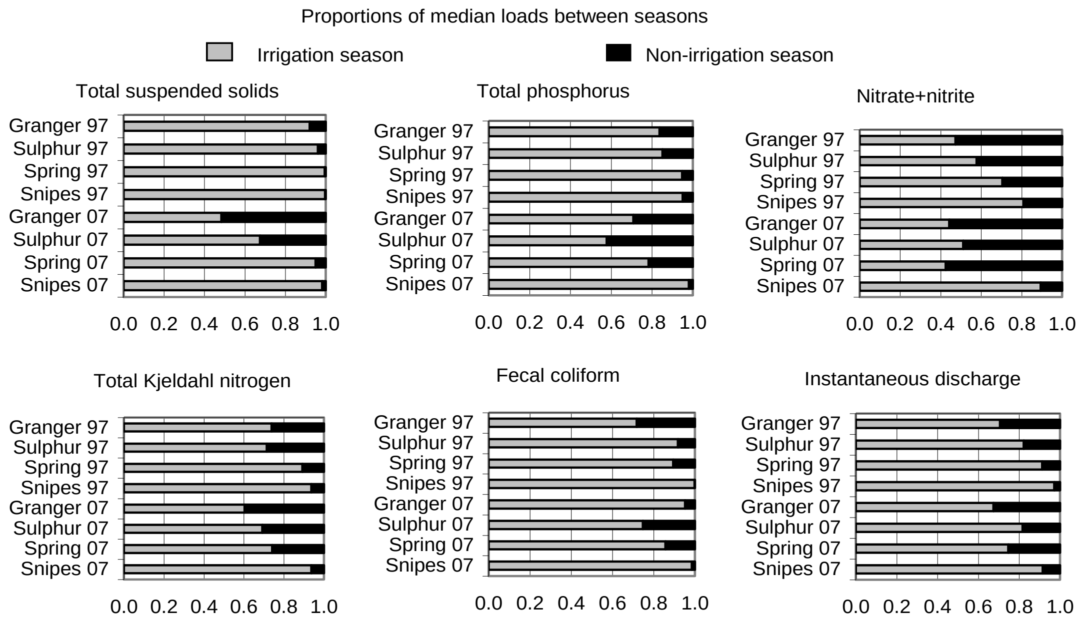


Figure 20. Proportions of median instantaneous loads during the irrigation and non-irrigation seasons, Granger, Sulphur, Spring, and Snipes, 1997 and 2007.

The relatively low non-irrigation season contribution in Snipes compared to the other waterways was also present when comparing nitrate+nitrite load data from 1997 to 2008 -- the non-irrigation season loads were significantly lower only in Snipes (figure 21).

Note: In figure 21, different scales were used between waterways; if the same scale had been used, Spring and Snipes would nearly disappear.

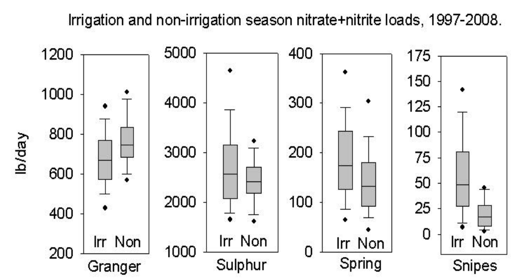


Figure 21. Nitrate+nitrite loads, Granger, Sulphur, Spring, and Snipes, 1997 to 2007/08 irrigation and non-irrigation seasons.

Granger and Sulphur sub-drains

The sampling sites within the Sulphur drainage effectively characterized baseflow hydrologic conditions. On each sampled day during the 1999 to 2005 non-irrigation seasons, the sum of the instantaneous discharges from the sub-drains was compared against the instantaneous discharge at the mouth, to determine what percentage of discharge at the mouth could be accounted for from the monitored sub-drains. The median of the sum of the sub-drains was comparable to median at the mouth Sulphur during the non-irrigation season (table 9). During the irrigation season, however, the sub-drains accounted for only 36% of the discharge at the mouth on half of the sampled days, reflecting the importance of canal spills to the hydrology of the wasteway.

Using the same approach in Granger, during the irrigation and non-irrigation seasons, the sub-drains accounted for roughly 74% and 65%, respectively, of the instantaneous discharge near the mouth. Roughly half of the imbalance may be from ungaged portions of the drainage basin (Zuroske, 2004), leaving roughly 15% unaccounted for.

Table 9. Median percent differences between loads near the mouths of Granger or Sulphur and the sum of loads from their sub-drains, 1999 to 2005.

Median percent of flow or load at mouth captured by sub-drain sampling	Discharge	Total suspended solids	Total phosphorus	Nitrate + nitrite	Total Kjeldahl nitrogen	Fecal coliform	Total dissolved solids
Granger							
Irrigation season	74	75	77	82	86	101	72
Non-irrigation season	65	72	70	85	72	61	71
Sulphur							
Irrigation season	36	50	65	70	67	71	56
Non-irrigation season	88	252	145	87	168	158	88

The load balances were roughly similar to water balances except during the non-irrigation season in the Sulphur drainage, when the cumulative load from the sub-drains was typically 2.5x the load of suspended solids from the mouth, 1.4x the load of phosphorus, 1.7x the load of total Kjeldahl nitrogen, and 1.6x the load of fecal coliform bacteria. Imbalances may be due to deposition of particulates in the wasteway (roughly 9 tons of total suspended solids per day), deposition and/or transformation of nutrients (32 pounds of total phosphorus and 137 pounds of total Kjeldahl nitrogen per day) and deposition or die-off of fecal coliform bacteria.

In a 1976-77 mass balance, the suspended sediment load during the irrigation season near the mouth of Sulphur was 3,800 tons more than sum of its sub-drains while it was 2,400 tons less during the non-irrigation season; total phosphorus also had a net deficit during the non-irrigation season (Boucher and Fretwell, 1982). Possible reasons suggested for the net deficits were in-channel deposition during the non-irrigation season, mainstem bed-load movement during the non-irrigation season, or uncertainty in load values; supporting evidence (more than 900 tons of sediment discharge on a single day in late March) for the first possibility was included in the report.

In 1974, irrigation season loads from the five major sub-drains in the Sulphur system accounted for 47, 67, 65, and 111% of the loads at the mouth for fecal coliform, total nitrogen, total phosphorus, and total suspended solids, respectively, while loads from the Sunnyside urban area contributed 49, 9, 20, and negligible percents, respectively (CH2M Hill, 1975).

Yields

From 1997 to 2008, irrigation season yields of total suspended solids were comparable between Granger, Sulphur, and Spring; Snipes had a lower yield than Granger or Sulphur (figure 22). Yields of fecal coliform, total phosphorus, total Kjeldahl nitrogen, and

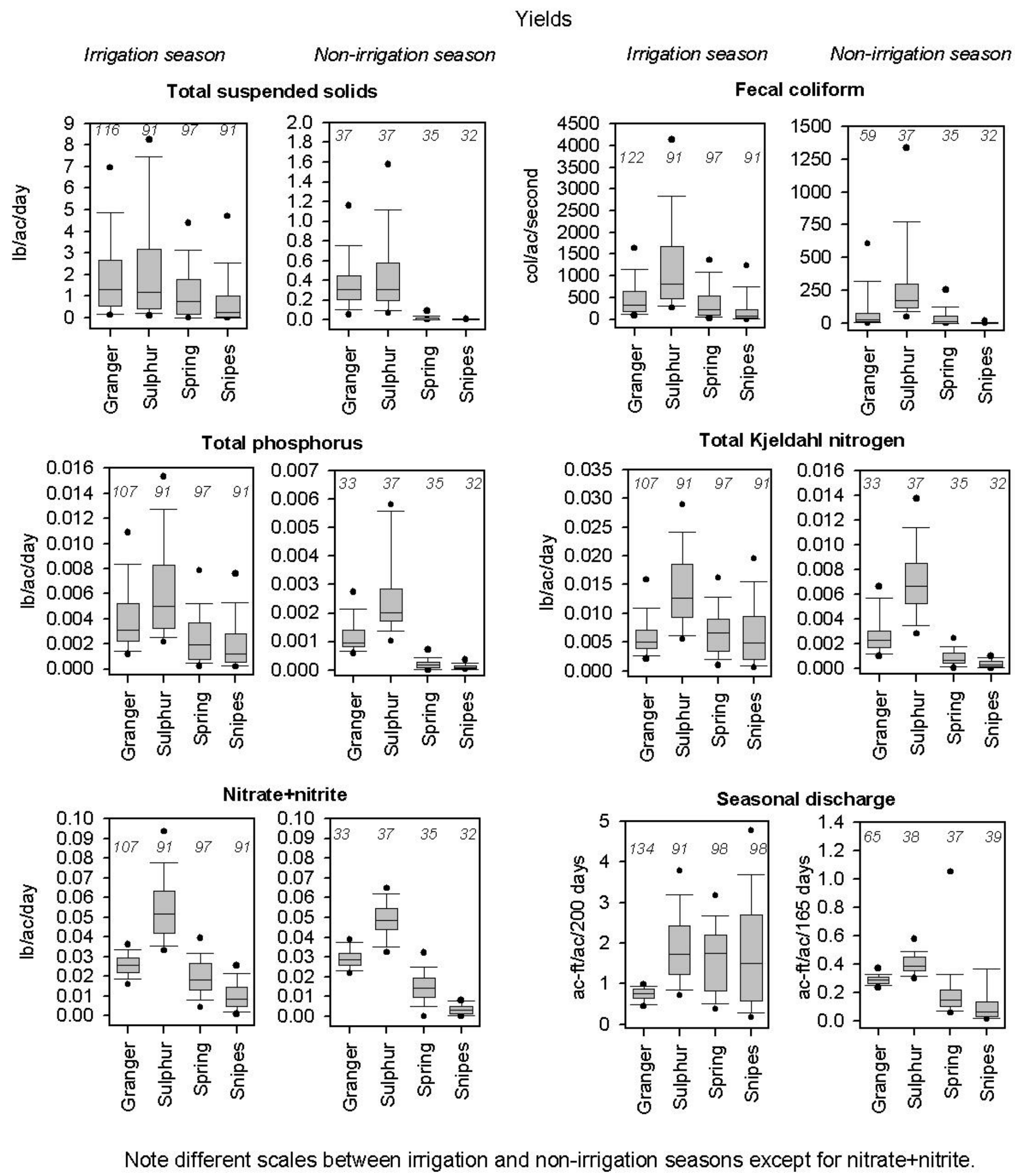


Figure 22. Yields, Granger, Sulphur, Spring, and Snipes, 1997 to 2007/08 irrigation and non-irrigation seasons.

nitrate+nitrite were comparable in Granger and Spring. Yields were comparable in Spring and Snipes except for lower nitrate+nitrite yields in Snipes. Discharge yields were lower in Granger than the other three waterways.

During the 1997-2007 non-irrigation seasons, yields of total suspended solids were comparable in Sulphur and Granger, and in Spring and Snipes. Fecal coliform yields were comparable in Granger and Spring. Yields of fecal coliform, total phosphorus, total Kjeldahl nitrogen, nitrate+nitrite, and discharge were higher in Sulphur than the other three waterways.

Compliance, progress, and, comparison to other watersheds

Three indicators of the relative conditions of these waters were considered: compliance with state standards, progress toward clean-up goals, and comparison to other watersheds.

Of the parameters monitored by RSBOJC, state standards exist for turbidity, dissolved oxygen, pH, temperature and fecal coliform bacteria (table 10). Because the temperature standard for the waterways is based on a 7-day average of the daily maximum value while only instantaneous values were evaluated in this report, the temperature standard was not used as a measure of compliance. Instead, 21 ºC, the daily maximum standard applicable to the Yakima River, was used as an indicator of relative severity.

Table 10. Washington State water quality criteria, 2008.

Parameter	Standard	Applicability
Turbidity	≤ 5 NTU above background when background is 50 NTU or less; when background is > 50 NTU, ≤ 10% increase above background.	All drains except Sulphur
	≤ 10 NTU above background when background is 50 NTU or less; when background is > 50 NTU, ≤ 20% increase above background.	Sulphur
Dissolved oxygen	≥ 8 mg/L, lowest 1-day minimum	All drains except Sulphur
	≥ 6.5 mg/L, lowest 1-day minimum	Sulphur until 2003
pH	Within the range of 6.5 to 8.5	All drains
Fecal coliform	Geometric mean ≤100 col/100 mL; top 10 percent value ≤ 200 col/100 mL	All drains except Sulphur
	Geometric mean ≤ 200 col/100 mL; top 10 percent value ≤ 400 col/100 mL	Sulphur

Turbidity. The turbidity standard is based on background conditions, defined as "….the biological, chemical, and physical conditions of the water body, outside of the area of influence of the discharge under consideration" (Chapter 173-201A-020 WAC). For this report, background was considered to be the average of turbidity in the Roza Canal and turbidity in the Sunnyside canal at their points of diversion. There are no perennial streams within RSBOJC's jurisdiction (Molenaar, 1985) to use for reference conditions.

Because waterways and canals were not sampled at the same frequency nor accounting for travel time, the data were screened to include only drain samples taken within eight days of canal samples, resulting in 88 to 90 paired values per drain (figure 23). In 1998 and 1999 turbidity values in the waterways were often much higher than the average canal values but after 2000 Sulphur, Spring, and Snipes became increasingly similar to the canal values (figure 23). From 1998 (when canal sampling began) through 2007, the percent of sampling days when each drain exceeded the averaged canal value by more than 5 NTU or, in the case of Sulphur, 10 NTU, were as follows: Granger 90%, Sulphur 41%, Spring 65%, and Snipes 24%.

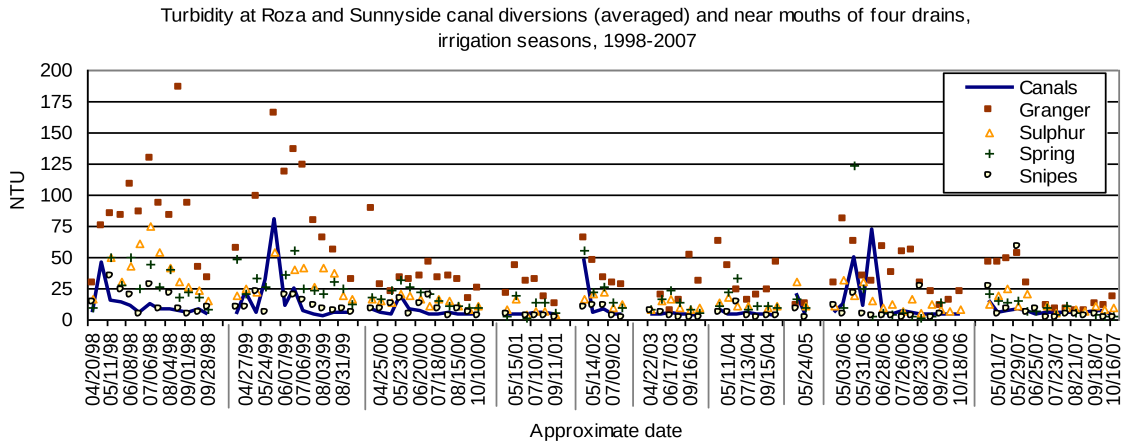


Figure 23. Turbidity in canal water and Granger, Sulphur, Spring, and Snipes, 1998 to 2007.

Fecal coliform. The fecal coliform standard was exceeded at the mouths of Granger, Sulphur and Spring during each irrigation season and during most non-irrigation seasons (table 11). Snipes met the geometric mean and top-10-percent criteria in all 11 non-irrigation seasons, Spring met both criteria in three non-irrigation seasons, and Granger in one non-irrigation season. Out of 92 values (four sites, all years, both seasons), 84% exceeded the top-10-percent criterion and 68% exceeded the geometric mean criterion.

Table 11. Geometric mean and top-10-percent values of fecal coliform concentrations, 1997 to 2008.

Irrigation Seasons									*Non-irrigation Seasons*								
	Geometric mean				**Top 10%**					**Geometric mean**				**Top 10%**			
Year	Granger	Sulphur	Spring	Snipes	Granger	Sulphur	Spring	Snipes	Year	Granger	Sulphur	Spring	Snipes	Granger	Sulphur	Spring	Snipes
1997	1419	1500	670	104	5600	3300	2500	390	1997-98	1248	461	709	15	4200	1600	3800	67
1998	1111	1059	504	238	2500	2100	980	610	1998-99	283	329	673	24	2000	1000	1900	130
1999	1351	800	371	91	3400	2000	5100	900	1999-00	193	278	475	11	530	790	1600	170
2000	781	457	231	61	3200	6100	1300	670	2000-01	165	383	94	17	260	900	180	28
2001	581	361	230	107	1500	510	1200	2000	2001-02	209	333	46	17	1700	420	310	60
2002	447	410	170	98	1800	1200	540	370	2002-03	87	355	96	7	320	430	310	44
2003	366	285	182	41	690	720	400	300	2003-04	70	329	180	26	240	470	1400	82
2004	374	353	128	37	1100	790	850	400	2004-05	57	314	32	24	210	530	66	22
2005	306	369	228	114	1800	770	1100	450	2005-06	121	632	53	14	1400	1300	660	71
2006	1050	593	265	122	3300	1600	2800	560	2006-07	160	1139	69	13	730	6900	140	16
2007	597	643	226	82	2600	3800	1700	2100	2007-08	55	580	41	17	180	2100	330	60
2008	482	402	209	76	1387	1700	710	2900									

Yellow cells: value met state water quality criteria.

Dissolved oxygen, pH, and temperature. The dissolved oxygen standard is based on the lowest daily value. Because 94% of the dissolved oxygen and pH measurements were obtained between 7 a.m. and noon, neither the minimum daily dissolved oxygen nor maximum daily pH values were likely captured. These waterways have high nutrient concentrations and, in some locations and times, abundant aquatic plants and algae. Despite the morning sampling times, more than 44% of the dissolved oxygen values

exceeded 100 percent saturation and more than 14% exceeded 110 percent saturation. As a measure of compliance, the instantaneous dissolved oxygen and pH values have limited applicability but were instead used as relative indicators of conditions. Similarly, as described above, a temperature of 21 ºC was used as an indicator of relative severity, not as a measure of compliance.

Abundant aquatic plant and algae growth in Spring, Sulphur, and Joint Drain 51.4.

Dissolved oxygen concentrations were less than 8 mg/L more often in July, August, and September than other months (table 12). In contrast, the percentage of pH values which exceeded 8.5 was highest in March (49%), comparable (22 to 31%) in April, November, December, January and February, and lowest in August. Temperatures exceeded 21 ºC more often in July and August (9%) than other months (0-2%).

Table 12. Dissolved oxygen, pH, and temperature conditions, all RSBOJC canal and drain sites, 1997 to 2008.

	Number of observations			Number of observations exceeding threshold			Percent of observations exceeding threshold		
Month	**# of Temp values**	**# of pH values**	**# of DO values**	**# DO values <8 mg/L**	**# pH values >8.5**	**# temp values >21° C**	**% of DO values <8 mg/L**	**% of pH values >8.5**	**% of temp values >21° C**
Apr	254	255	248	1	75	0	0.4	29.4	0.0
May	395	395	383	4	56	3	1.0	14.2	0.8
Jun	432	431	383	17	41	8	4.4	9.5	1.9
Jul	438	438	365	55	26	40	15.1	5.9	9.1
Aug	483	481	353	48	17	44	13.6	3.5	9.1
Sept	419	415	354	25	24	3	7.1	5.8	0.7
Oct	311	311	311	12	26	0	3.9	8.4	0.0
Nov	173	173	171	7	42	0	4.1	24.3	0.0
Dec	161	157	161	1	35	0	0.6	22.3	0.0
Jan	177	177	165	1	42	0	0.6	23.7	0.0
Feb	183	182	180	2	57	0	1.1	31.3	0.0
Mar	161	160	143	3	78	0	2.1	48.8	0.0

State clean-up goals.

Two Total Maximum Daily Loads (TMDLs), or water quality clean-up plans, developed by the Department of Ecology established numerical goals. The Lower Yakima River Suspended Sediment TMDL established a 2002 turbidity goal of 25 NTU in 90% of the

data for the mouths of the waterways. Sulphur, Spring, and Snipes met the goal; Granger did not (figure 5). The Granger Drain Fecal Coliform Bacteria TMDL established an interim goal for all points within Granger Drain of 510 col/100 mL top-10-percent value by 2007. This goal was met at the mouth of Granger Drain during the non-irrigation seasons of 1999, 2000, 2002-04, and 2007 but not during any irrigation season (table 11).

Conditions in other surface waters.
In Lower Crab Creek, south of Moses Lake, total suspended solids yields were 0.27 lb/ac/day in 1975 with 64% furrow irrigation, decreasing to 0.15 lb/ac/day in 1985 with about 49% furrow irrigation (Williamson *et al*, 1998). In the Quincy-Pasco sub-basin, nine drainages had suspended sediment yields in 1994 of roughly 0.35, 0.4, 0.6, 0.8, 0.9, 9.0, and 17 lb/ac/day (Ebbert and Moon, 1998). In range and forest-dominated watersheds in the Nevada Basin, suspended sediment yields were 12 tons/mi^2/year (0.10 lb/ac/day) at a headwater site, 630 ton/mi (5.4 lb/ac/day) in the drainage area with the highest percentage of urban landuse (but also two avalanches which could have affected yield), and 140 ton/mi^2 (1.2 lb/ac/day) in the drainage with the most agricultural land (Kilroy *et al*, 1997). In Granger, Sulphur, Spring, and Snipes, yields of total suspended solids ranged from 0.4 to 9.6 lb/ac/day from 1997 through 2000 irrigation seasons, and 0.02 to 1.3 lb/ac/day from 2001 through 2008 irrigation seasons.

Based on nationwide data, the U.S. Geological Survey (USGS) ranked high, median, and low annual yields of total nitrogen as greater than 1.3 lb/ac/yr, 1.3-0.4 lb/ac/yr, and less than 0.4 lb/ac/year and yields of total phosphorus as greater than 0.1 lb/ac/yr, 0.1-0.03 lb/ac/yr, and less than 0.03 lb/ac/yr (units converted from kg/km^2) (Mueller and Spahr, 2006). For Granger, Sulphur, Spring, and Snipes, the annual total nitrogen yields were estimated by multiplying the sum of the median yields for nitrate+nitrite and total Kjeldahl nitrogen for the irrigation season by 200 days and 165 days for the non-irrigation season. Estimated annual yields ranged from 0.6 lb/ac/year (Snipes in 2001 drought) to 33.2 lb/ac/yr (Sulphur in 1997) total nitrogen and 0.04 (Snipes in 2001) to 2.72 (Granger in 1997) total phosphorus.

In undeveloped basins throughout the U.S., annual nitrate yields correlated well to wet deposition of total inorganic nitrogen (nitrate plus ammonia as N) from the atmosphere; average annual basin yield of nitrate from 12 basins in the arid West (the area with the smallest atmospheric deposition) was only 8.3 kg/km^2/year (Clark *et al*, 2000), or 0.02 lb/ac/year. Annual basin yields of total phosphorus in undeveloped basins ranged from 1 to 82 kg/km^2 or 0.15 lb/ac/year. Estimated annual nitrate yields from Granger, Sulphur, Spring and Snipes were 2-130x greater than in undeveloped basins. Estimated annual median phosphorus yields in Snipes, however, were slightly less than in undeveloped basins in 2001, 2003, and 2005, and in Spring were slightly less in 2006 and 2007.

Out of five agricultural basins in the U.S., DR2 (a Granger sub-drain) had the highest yield of nitrate, total nitrogen, and orthophosphate – 2x or more than the next highest basin (Domagalski *et al*, 2008). In the Trinity River Basin in Texas, the four-year average yields of nitrogen were 6.7 kg/ha/yr (5.97 lb/ac/yr) for Little Elm Creek (dominated by agriculture) and 2.8 kg/ha/yr (2.5 lb/ac/yr) for Clear Creek (largely pasture and range) (Van

Metre and Reutter, 1995). In Granger, Sulphur, Spring, and Snipes, estimated annual total nitrogen yields ranged from 0.6 lb/ac/year (Snipes 2001 drought) to 33.2 lb/ac/yr (Sulphur in 1997). In comparison to rivers and streams in the Columbia River and Puget Sound basins in 2000, Granger Drain was in the 4th quartile (upper 25%) for total nitrogen yields and the 3rd quartile for total phosphorus yields (Wise *et al*, 2007).

Relations between variables

The relationship between total suspended solids concentrations and turbidity (figure 25) was strong and similar to that observed in the Department of Ecology's Total Maximum Daily Load assessment, when considering lower concentrations. Equation A, below, was the relationship found in 1994-95, from samples throughout the lower basin including Yakima River and tributary sites, while equation (B) was based on samples from irrigation waterways from 1997-2007:

(A) log10 turbidity = 0.871*log10 total suspended solids - 0.145

(B) log10 turbidity = 0.771*log10 total suspended solids + 0.0206.

The TMDL's goal of 56 mg/L total suspended solids calculates to 25 NTU using the 1994-95 data and 23 NTU using the 1997-2007 data, a negligible difference.

E. coli concentrations related strongly to fecal coliform concentrations when considering all waterways (figure 24). Fecal coliform related weakly to total suspended solids concentrations.

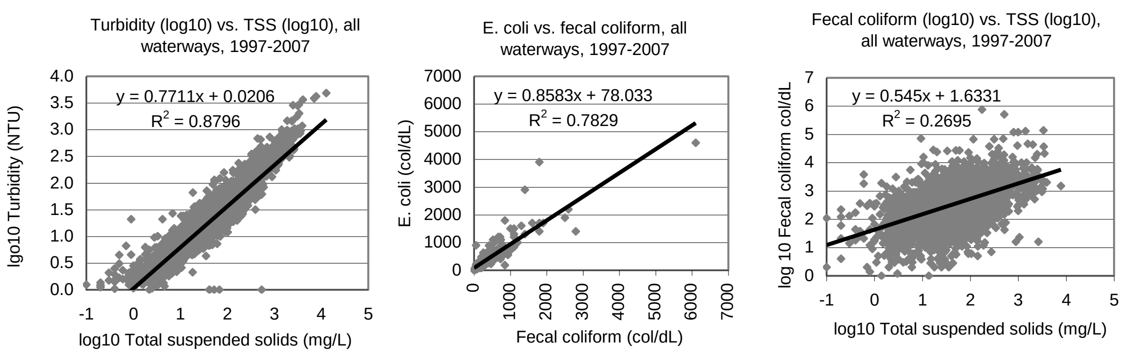
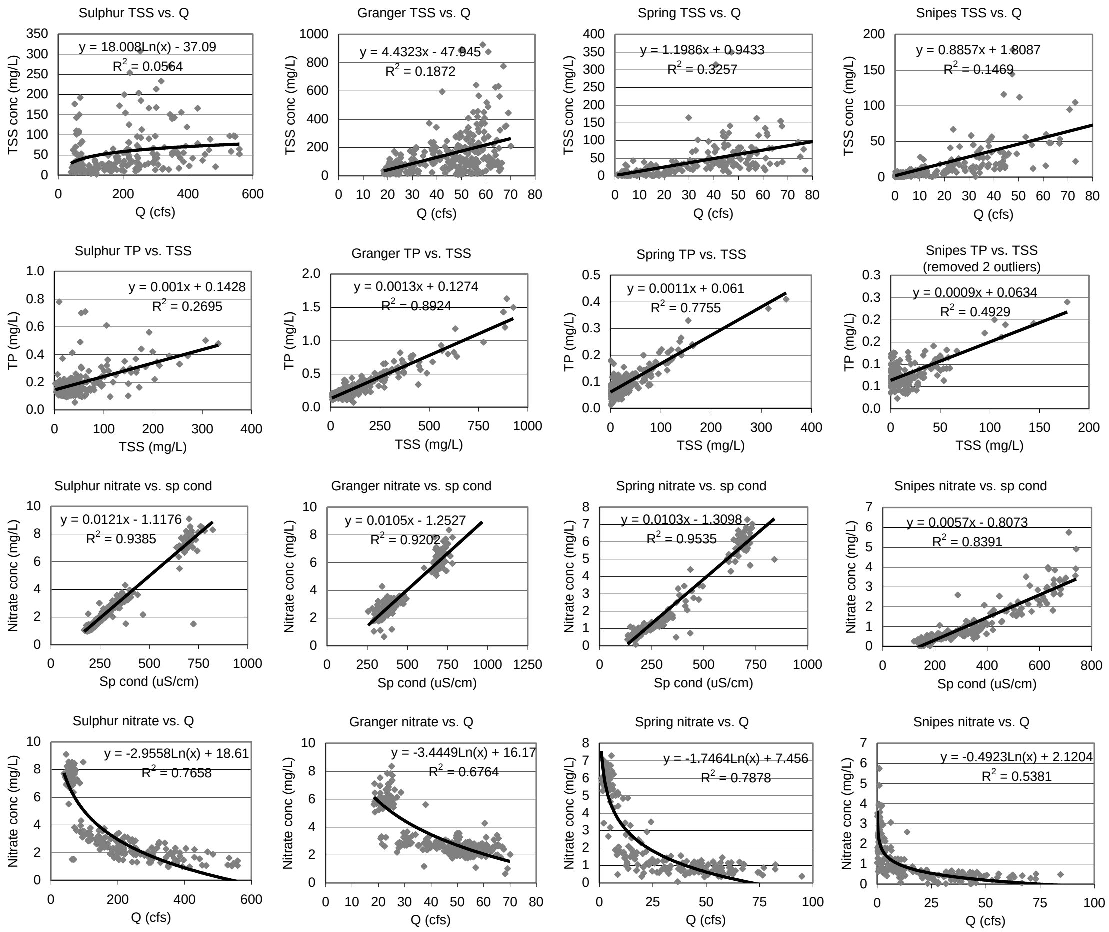


Figure 24. Regressions of turbidity vs. total suspended solids, *e. coli* vs. fecal coliform, and fecal coliform vs. total suspended solids, all waterway sites, 1997 to 2007.

When considering the four major waterways individually, total phosphorus related to total suspended solids in Granger and Spring, and in Snipes when two outliers were removed, but not in Sulphur (figure 25). Nitrate+nitrite related strongly to specific conductance. Instantaneous discharge was inversely related to nitrate+nitrite concentrations but was not related to turbidity, total suspended solids, total phosphorus, total Kjeldahl nitrogen, or fecal coliform concentrations. The poor relationship between discharge and total suspended solids was likely a reflection of the highly-managed nature of these waterways. Natural streams generally have a good relationship between discharge and total suspended solids (Simon and Heins, 2005).



Abbreviations: *TSS* total suspended solids, *Q* instantaneous discharge, *TP* total phosphorus, *nitrate* nitrate+nitrite, *Sp cond* specific conductance.

Figure 25. Linear regressions in four waterways, various constituents, 1997 to 2007.

Factors influencing water quality

Delivery water

Amount

In the water-short years of 2001 and 2005, total suspended solids concentrations and turbidity and instantaneous discharge values were lower than during the water-available years of 2000 and 2002, except discharge in Snipes was comparable between sets of years (figure 26). Nitrate+nitrite concentrations were lower in water-short years than water-available years in Granger and Sulphur but not in Spring or Snipes; specific conductance was greater in all waterways in water-short years except Spring. Fecal coliform, total phosphorus, and total Kjeldahl nitrogen concentrations were comparable between sets of years, except total phosphorus was lower in Spring in water-short years.

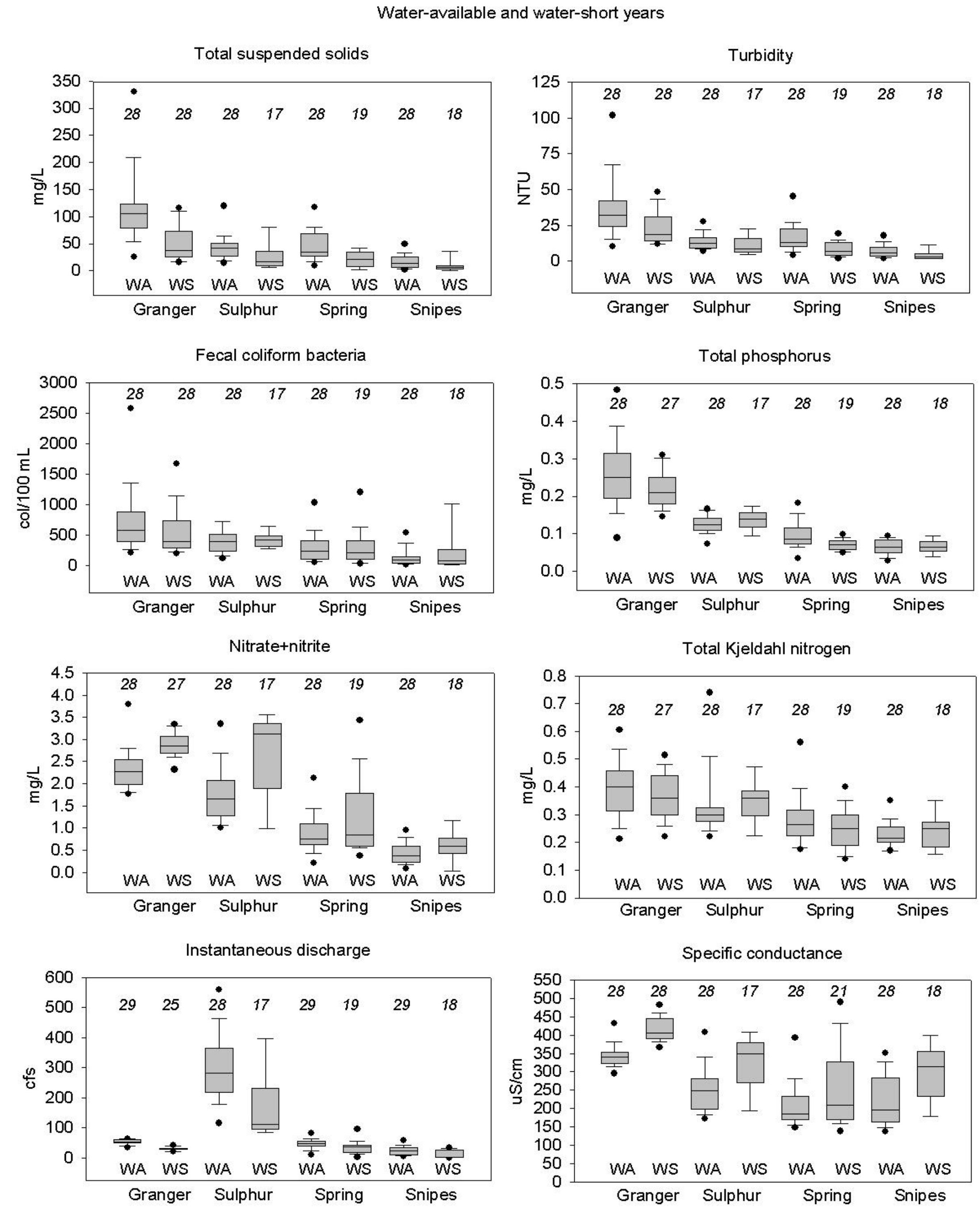


Figure 26. Irrigation seasonal concentrations and values, mouths of four waterways, water-available (WA) years of 2000 and 2002 and water-short (WS) years of 2001 and 2005.

Quality

The quality of water in irrigation waterways related poorly to the quality of delivery water. The median concentrations of most constituents in most waterways were 2x to 10x greater than at the canal diversions (table 13), indicative of the relative importance of on-farm

practices compared to delivery water quality. In comparison, in 1976 "constituent concentrations in the drains were generally 5 to 20 times greater than the delivery waters" (Boucher and Fretwell, 1982). In 1979-81, average total suspended solids concentrations in delivery water to small drainages in Sulphur were 99, 32, and 24 mg/L (Boucher, 1983) – higher than any median value from 1997-2007.

During recent years in Snipes, however, median turbidity, total suspended solids, and total phosphorus were often comparable to canal concentrations, and in 2006 and 2007, turbidity and total suspended solids in Spring also were comparable to concentrations in the canals. Therefore, the turbidity in the Roza and Sunnyside canals (averaged between the two canals) was regressed against turbidity in Spring or Snipes (of the samples taken within eight days of the canal samples). Turbidity in Spring was weakly related to canal turbidity – only 30% of the variability in turbidity in Spring during the 1998-2007 irrigation seasons was explained by variability in turbidity in the canal; in other waterways there was no relation (r^2 less than 0.2). For total phosphorus, there was no relation (r^2 less than 0.1) between concentrations in the canal and in Spring or Snipes.

Table 13. Median concentrations and values in Granger, Sulphur, Spring, Snipes, and two canal diversion sites, 1998 to 2007 irrigation seasons.

	Granger	Sulphur	Spring	Snipes	Roza	Sunnyside	Granger	Sulphur	Spring	Snipes	Roza	Sunnyside	Granger	Sulphur	Spring	Snipes	Roza	Sunnyside
	Turbidity (NTU)						Total suspended solids (mg/L)						Fecal coliform (col/100 mL)					
1998	83	31	25	10	6	10	300	96	67	35	13	23	1100	1100	660	250	57	115
1999	79	37	25	9	6	7	264	97	80	19	11	18	1400	885	365	97	74	69
2000	32	14	16	8	4	6	109	49	43	17	9	15	740	395	245	73	29	51
2001	21	8	12	3	4	6	50	13	28	6	7	11	600	385	225	115	29	45
2002	29	14	13	5	6	5	101	35	33	10	9	17	410	410	170	110	37	34
2003	20	10	13	3	4	4	62	27	36	4	5	7	340	300	210	59	20	24
2004	25	11	11	3	5	4	77	25	34	10	7	7	345	365	88	30	36	24
2005	16	12	10	3		7	35	28	24	4	*	13	275	390	210	140	*	25
2006	34	11	5	4	5	6	126	26	7	7	5	10	1100	620	265	130	22	47
2007	15	11	7	5	5	7	23	19	9	5	3	9	640	410	310	41	34	42
	Total phosphorus (mg/L)						Nitrate+nitrite (mg/L)						Total Kjeldahl nitrogen (mg/L)					
1998	0.53	0.23	0.13	0.09	0.05	0.07	2.4	2.4	0.9	0.5	0.2	0.2	0.63	0.46	0.31	0.26	0.21	0.19
1999	0.50	0.19	0.14	0.08	0.05	0.06	2.1	1.8	0.6	0.4	0.2	0.1	0.54	0.42	0.32	0.27	0.19	0.16
2000	0.25	0.12	0.10	0.07	0.04	0.05	2.3	1.5	0.7	0.3	0.1	0.1	0.35	0.30	0.26	0.22	0.15	0.17
2001	0.22	0.15	0.08	0.07	0.04	0.06	2.9	3.3	0.8	0.6	0.2	0.2	0.38	0.37	0.25	0.26	0.17	0.22
2002	0.25	0.15	0.08	0.06	0.04	0.05	2.2	3.3	0.8	0.4	0.2	0.1	0.41	0.31	0.28	0.21	0.21	0.18
2003	0.21	0.12	0.08	0.06	0.04	0.06	2.2	1.8	0.8	0.8	0.2	0.2	0.39	0.36	0.31	0.24	0.16	0.15
2004	0.25	0.12	0.09	0.07	0.06	0.06	2.4	2.3	1.0	0.6	0.3	0.2	0.42	0.39	0.30	0.27	0.20	0.16
2005	0.20	0.13	0.09	0.07	*	0.08	2.8	2.3	0.8	0.7	*	0.3	0.34	0.46	0.29	0.23	*	0.22
2006	0.31	0.15	0.07	0.07	0.05	0.06	2.7	3.0	1.6	0.7	0.2	0.2	0.48	0.41	0.36	0.27	0.21	0.20
2007	0.21	0.13	0.07	0.06	0.04	0.06	2.7	2.3	1.4	0.5	0.1	0.1	0.41	0.33	0.33	0.25	0.19	0.21

* Roza 2005 medians were not calculated because there were only 2 values.

Precipitation

The minor differences in precipitation between years (figure 3) did not correspond to the pattern or magnitude of differences between years in total suspended solids concentrations in the waterways (figure 5). Linear regressions between daily precipitation and total

suspended solids concentrations in Sulphur showed no relation (r^2 of 0.02) between these variables either during the irrigation or non-irrigation season.

Significant precipitation events have explained isolated incidences in the past. For example, on February 16-20, 1980 one storm produced 11-51% of suspended sediment load from April 1979 to October 1981 in small tertiary drains to Sulphur (Boucher, 1983). The maximum daily precipitation recorded from 1997 to 2008 at Harrah was 1.15 inches on December 14, 2006. Only one site, near the mouth of Granger, was sampled within a week after that event. Yet on December 20, when the site was sampled, turbidity was less than from a sample two weeks earlier.

Land use and physical factors

In 2000, Spring/Snipes had the lowest proportion of rill irrigation (29%) and highest proportion of drip (21%) compared to Granger and Sulphur with 40-41% rill and 3-5% drip. Soils in the Granger and Sulphur drainage basins were dominantly silt loams; however, Sulphur had more fine sandy loams which are more erodible but settle in water more quickly than silt loams (Zuroske, 2004). Yet yields of total suspended solids during the irrigation season were comparable in Spring, Granger and Sulphur (table 14).

Specific soils data were not available for Spring and Snipes. A generalized assessment of each total drainage basin found 80 and 87% high permeability deposits and 13 and 20% basalt, respectively (Smith *et al*, 2006). Snipes had the lowest yield of total suspended solids and the highest proportion of impermeable surficial deposits.

Based on a Department of Ecology survey during 1998-2003, 29% of the irrigated acres in Granger and 12% in Sulphur were owned by dairies (Laurie Crowe, South Yakima Conservation District, personal communication, February 2004) and there were 20, 24, 2, and 0 dairies in Granger, Sulphur, Spring and Snipes drainages, respectively (Washington State Department of Ecology, 2003). Yet irrigation season yields of total Kjeldahl nitrogen, total phosphorus, and fecal coliform were comparable in Granger and Spring. No data were available on the number of non-dairy livestock animals (beef cattle, horses, goats, etc) in each of these drainages. One additional source of unknown magnitude of fecal coliform in Spring and Snipes are beavers. A 2001 survey found 17 beaver ponds in Spring and numerous in Snipes; the report did not mention beaver ponds in Granger or Sulphur (Romey and Cramer, 2001).

Overall watershed slopes within the irrigated portions (highest elevation minus lowest elevation divided by straight-line length roughly perpendicular to contour lines) were 0.9, 0.6, 1.9, and 2.9% in Granger, Sulphur, Spring, and Snipes. Field slopes were similar in Granger and Sulphur (Zuroske, 2004); Spring and Snipes had negligible acres with slopes of less than one 1% (Daly, 1998) compared to 28% in Granger and 37% in Sulphur. Similarly, the gradients of the waterways were highest in Spring and Snipes and lowest in Granger and Sulphur. Neither watershed slope, field slope, nor waterway gradient corresponded to total suspended solids yields during the irrigation season, which were comparable in Granger, Sulphur, and Spring, or during the non-irrigation season, which were comparable in Sulphur and Granger, lower in Spring, and least in Snipes.

Table 14. Drainage area characteristics and water quality indicators.

Drainage area	**Granger**	**Sulphur**	**Spring**	**Snipes**
Drainage area characteristics (excerpts from table 1)				
Percent acres irrigated	66	48	40	25
Major crops	27% tree fruit, 25% corn, 19% pasture, 11% grapes	25% pasture, 23% grapes, 17% tree fruit, 11% corn	33% grapes, 27% tree fruit, 17% pasture, 14% hops	
Number of dairies	20 (29% of irrigated acres owned by dairies)	24 (12% of irrigated acres owned by dairies)	2	0
Irrigation types	54% sprinkler, 41% rill, 5% drip	48% sprinkler, 40% rill, 3% drip	29% rill, 51% sprinkler, 21% drip	
Soils	90% silt loam	57% silt loam, 20% fine sandy loam	87% high permeability deposits, 13% basalt	80% high permeability deposits, 20% basalt
Drain substrate	Silt, sand	Silt, sand	Gravel, cobble	Gravel, cobble
Drain gradient (%)	0.3	0.3	0.9	1
Water quality indicators: 25th, 50th, and 75th percentile* yields				
Yields, 1997 to 2008 irrigation seasons				
Total suspended solids (lb/ac/day)	25th%ile 0.6 50th%ile 1.3 75th%ile 2.7	0.5 1.2 3.1	0.2 0.8 1.8	0.04 0.25 0.97 (~ to Spring; < Granger or Sulphur)
Fecal coliform (col/sec)	25th%ile 186 50th%ile 330 75th%ile 644	474 807 1686	107 222 539	24 72 225 (<Granger)
Total phosphorus (lb/ac/day)	25th%ile 0.002 50th%ile 0.003 75th%ile 0.005	0.003 0.005 0.008	<0.001 0.002 0.004	<0.001 0.001 0.002 (<Granger)
Nitrate+nitrite (lb/ac/day)	25th%ile 0.022 50th%ile 0.026 75th%ile 0.029	0.042 0.052 0.063	0.014 0.019 0.026	0.005 0.009 0.015
Total Kjeldahl nitrogen (lb/ac/day)	25th%ile 0.004 50th%ile 0.005 75th%ile 0.007	0.009 0.013 0.019	0.003 0.007 0.009	0.002 0.005 0.009
Discharge (ac-ft/ac/season)	25th%ile 0.7 50th%ile 0.8 75th%ile 0.9	1.3 1.7 2.4	0.9 1.7 2.2	0.6 1.5 2.7
Yields, 1997 to 2007 non-irrigation seasons				
Total suspended solids (lb/ac/day)	25th%ile 0.2 50th%ile 0.3 75th%ile 0.4	0.2 0.3 0.6	0.003 0.006 0.022	<0.001 0.002 0.003
Fecal coliform (col/sec)	25th%ile 16 50th%ile 33 75th%ile 78	121 176 294	4 18 53	<1 1 2.5
Total phosphorus (lb/ac/day)	25th%ile <0.001 50th%ile <0.001 75th%ile 0.001	0.002 0.002 0.003	<0.0001 <0.001 <0.001	<0.0001 <0.0001 0.0001
Nitrate+nitrite (lb/ac/day)	25th%ile 0.026 50th%ile 0.029 75th%ile 0.032	0.044 0.049 0.054	0.010 0.014 0.019	0.001 0.003 0.005
Total Kjeldahl nitrogen (lb/ac/day)	25th%ile 0.002 50th%ile 0.002 75th%ile 0.003	0.005 0.007 0.008	<0.001 <0.001 0.001	<0.001 <0.001 <0.001
Discharge (ac-ft/ac/season)	25th%ile 0.26 50th%ile 0.29 75th%ile 0.31	0.35 0.39 0.45	0.10 0.15 0.22	0.03 0.06 0.13

** Percentiles calculated by Excel.*

Note: Colors indicate relative conditions from highest to lowest. highest mid mid lowest
The same color for more than one site on a single row indicates the distribution of the data were comparable.

During the non-irrigation season, yields were lower in Spring and Snipes than in Granger and Sulphur of all constituents except for fecal coliform in Spring, which was comparable to Granger. Spring and Snipes had no urban areas (and thus no stormwater drains), while Sulphur encompassed roughly 4,500 acres of urban areas and Granger 500 acres. Spring and Snipes also had higher percentages of surficial basalt, coarser waterway substrates, and, for Snipes, considerable lower proportion of irrigated acres within the drainage area.

Management practices

Delivery system

In July 2005, the construction of a re-regulation reservoir at canal mile 59.29, near Whitstran, was completed to increase delivery efficiency of the Sunnyside Canal. As a result, significantly less operational spill water was released into Spring in 2006-08. Comparing conditions in Spring in two non-drought years before (2000 and 2002) and after (2006 and 2007) the project found significant decreases in instantaneous discharge and concentrations of total suspended solids and total phosphorus and increased concentrations of total Kjeldahl nitrogen and nitrate+nitrite (figure 27). Median loads decreased by 93, 47, 75, 53 and 16% for total suspended solids, fecal coliform, total phosphorus, total Kjeldahl nitrogen, and nitrate+nitrite, respectively.

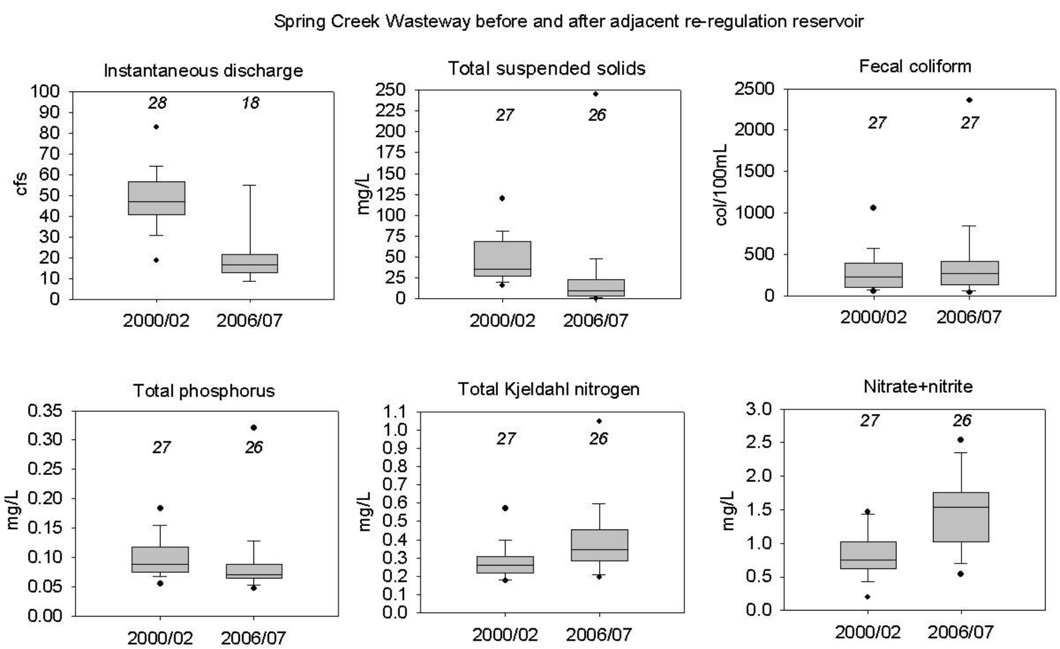


Figure 27. Irrigation seasonal concentrations and discharge in Spring Creek Wasteway before (2000 and 2002) and after (2006 and 2007) installation of adjacent re-regulation reservoir.

On-farm irrigation improvements

The types of irrigation improvements made by growers in the lower valley during these years varied widely. Examples include converting furrow to sprinkler irrigation systems, using polyacrylamide in furrows to flocculate soil particles (decreasing turbidity in water leaving the field), installing pump-back systems to capture water leaving the furrows to reuse on the same farm, construction of sedimentation ponds, and changing the timing, frequency or duration of irrigation sets.

No data were available on the rate of adoption of these voluntary practices during these years by all landowners within these drainages. However, agencies providing public funds to assist landowners did keep records. The USDA Natural Resources Conservation Service's Environmental Quality Incentives Program provided $8,588,233 from 1997 to 2008 in Yakima County to irrigation practices on 39,028 acres; irrigation systems were converted from furrow to sprinkler on approximately half of these acres while half of the acres had improved management practices (e.g. irrigation scheduling) applied to them. From 2000 to 2008, the Roza-Sunnyside Board of Joint Control provided $11,479,100 in low-interest loans for on-farm irrigation system upgrades on 15,718 acres throughout its jurisdiction. In some cases, loan money was used in conjunction with cost-share funds, so some acres were counted by both programs. The total acres and dollars spent from 1997 to 2008, however, still provide a sense of the level of effort undertaken: 35,700 acres of on-farm irrigation system improvements and 20,000 acres of improved irrigation water management for a cost of $20,067,033 over a 12-year period. Growers participating in the cost-share and loan programs reflected the diversity of agriculture in the lower valley – no single crop type or size of farm dominated the programs.

The cost-share and loan participation rates did not quantitatively relate to the rates of water quality improvements. Funding levels and the number of improved acres were lower in 1997 to 1999, when water quality conditions improved the fastest, than in 2000 to 2008 (figure 28), when water quality improvements slowed. Possible reasons include varying effectiveness of the same practice on different fields (e.g., converting from furrow to sprinkler on five percent slopes would result in larger improvements than on one percent slopes, all else being equal), the amount of unfunded and untracked irrigation improvements, diminishing

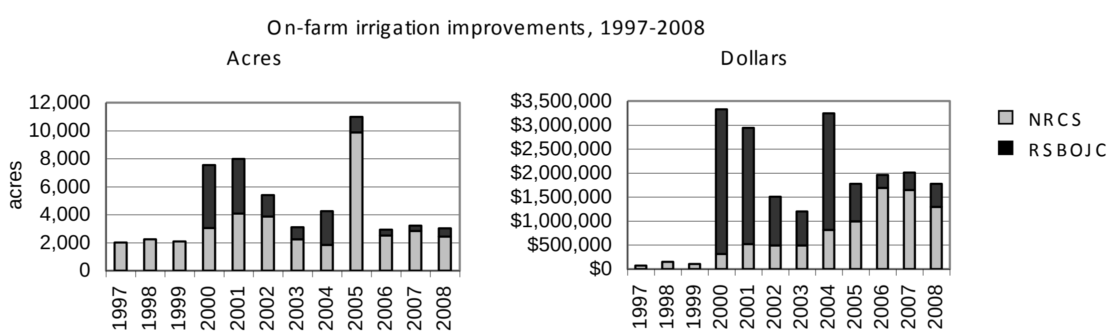


Figure 28. Acres and dollars of partially publicly-funded irrigation improvement practices in the lower Yakima Valley, by year.

returns common to many environmental improvements, and the technical complexity of quantifying the relationship between conservation efforts and their effects on water quality in watersheds with diverse cropping and irrigation practices.

In addition to the availability of cost-share and low-interest loans discussed above, several factors influenced growers' decisions to improve irrigation practice during these years, including: (1) the increasing number of pressurized laterals, which enable some growers to install sprinkler systems without expensive pumps; (2) the Roza-Sunnyside Board of Joint Control's water quality policy, which reduced water deliveries to fields from which highly turbid runoff repeatedly occurred; (3) the passage of the state's Dairy Nutrient Management Act, which required dairies to develop nutrient management plans and resulted in cost-share funding of improved irrigation and nutrient management practices on dairies; (4) decades of technical assistance provided to growers by the Natural Resources Conservation Service, Washington State University Cooperation Extension, and local conservation districts; and (5) farmers informally encouraging other farmers to change their irrigation practices in order to support commonly-held values (e.g., peer pressure).

Influence of waterways on the Yakima River

Turbidity

In 1977, CH2M Hill described a portion of the lower Yakima River as follows: "Between Sunnyside Dam and Mabton, a distance of 45 miles, the summer flows are significantly reduced by diversion, the gradient flattens, water temperatures rise, and nutrient- and sediment-rich return flows are added to produce river water that cannot meet even the lowest Washington quality standards. At this point, the river is unfit for most water activities from both health and aesthetic standpoints." (CH2M Hill, 1977).

In contrast, in 2003 the Department of Ecology determined the Yakima River met the turbidity goal of less than a 5 NTU increase between the City of Yakima (upstream of the major waterways in the lower valley) and Benton City (downstream of the major waterways) from late June (after snowmelt ended) through October; and further, when considering all of the 2003 data, found no statistically significant difference between the two sites (Coffin *et al*, 2006). Sediment loads in the lower Yakima River had been significantly reduced since their prior study in 1995, which the authors attributed to implementation of the state's water quality clean-up plan (which focused on improving canal delivery efficiency and on-farm irrigation practices). The difference over time was confirmed by RSBOJC's longer-term sampling which found the median cumulative loads from the waterways decreased from 255 to 25.6 tons per day from 1997 to 2007 (figure 29). Based on ambient monthly monitoring conducted by the Department of Ecology in the Yakima River near Benton City, the median turbidity during the irrigation season declined by 14 NTU from 1995 to 2005 (figure 29). River conditions were evaluated through 2007 instead of 2008 because the 2008 data from the Department of Ecology were not yet finalized when this report was being prepared.

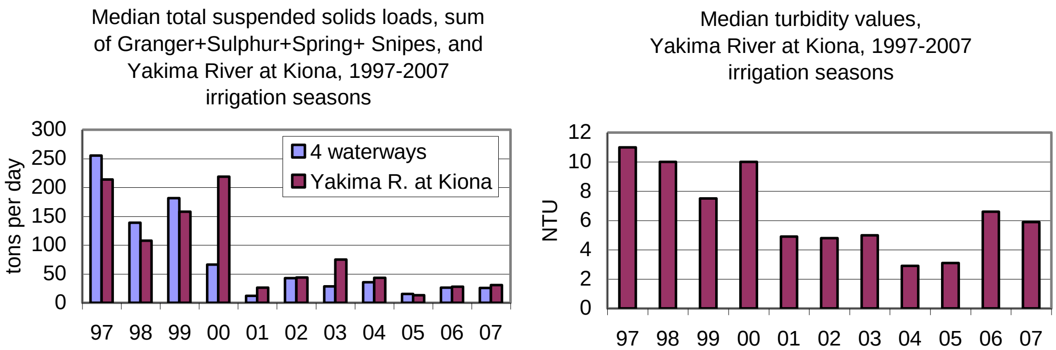


Figure 29. Sum of median total suspended solids loads from four waterways (RSBOJC data), and median total suspended solids loads and turbidity, Yakima River at Kiona (Dept. of Ecology data), 1997 to 2007 irrigation seasons.

Fecal coliform

Fecal coliform concentrations in irrigation waterways routinely and frequently exceeded state standards from 1997 to 2008 but little data was available on the impact on the river. The only site routinely monitored by the Department of Ecology in the lower Yakima River downstream of the major irrigation waterways is at Kiona. Geometric mean concentrations in the Yakima River at Kiona from 1994 to 2007 ranged from 7 to 169 col/100 mL with two years (1995 and 1996) exceeding the criteria while the top-10% concentrations ranged from 22 to 480 col/100mL, with two years (1997 and 1999) exceeding the criteria (Washington State Department of Ecology, 2009). However, Kiona is 12 to 53 miles downstream of the four major waterways discussed in this report, limiting its usefulness as an indictor of impacts from these waterways. Based on basin-wide synoptic sampling in 1999 and 2000, USGS concluded that agricultural tributaries were likely the sources of fecal coliform in the basin but found few strong spatial patterns or significant changes since a 1988 synoptic, in part due to high (order-of-magnitude) variability in replicate samples (Morace and McKenzie, 2002).

Nutrients

Irrigation waterways have been major sources of nutrients to the lower Yakima River for decades. In the mid-1970's, a rough nutrient balance found irrigation return flows contributed 66% of total nitrogen and 33% of total phosphorus loads in the Yakima River at Kiona (CH2M Hill, 1977). In 1988, Granger Drain, Satus Creek, South Drain, and Sulphur Creek Wasteway accounted for 67% of total nitrogen and 74% of total phosphorus loads in the river at Grandview (Morace *et al*, 1999). In 2004, 86% of the total nitrogen and 70% of the total phosphorus loads in the Mabton reach of the river were derived from irrigation tributaries (Wise *et al*, 2009).

The pattern of substantial reductions in total phosphorus loads from the four waterways from 1997 to 2001 did not correspond to the pattern of total phosphorus concentrations and

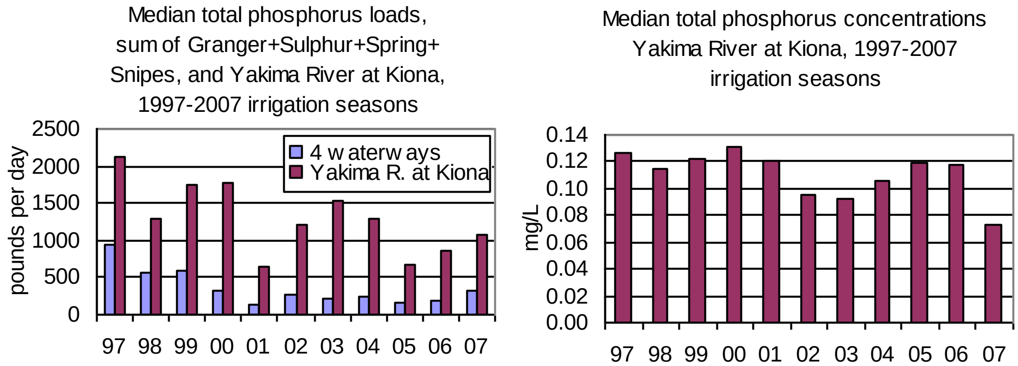


Figure 30. Sum of median total phosphorus loads from four waterways (RSBOJC data), and median total phosphorus loads and concentrations, Yakima River at Kiona (Dept. of Ecology data), 1997 to 2007 irrigation seasons.

loads in the lower Yakima River at Kiona during the same years (figure 30). Concentrations and loads, however, did decline in the waterways and the river over time.

Other key indictors of eutrophic conditions – the presence of nuisance plant or algae growth and resultant low dissolved oxygen and high pH values – were briefly mentioned in early studies: in 1973, 'dense growths of unsightly and offensive aquatic organisms' were noted (CH2M Hill, 1977); low phytoplankton densities measured in 1992 were thought to be due to light limitation (Morace *et al*, 1999); and in 1999-2000, 'heavy growths of algae and rooted aquatic plants have been observed' (Fuhrer *et al*, 2004). High biomass of aquatic plants occurred in the Kiona reach in 2004 and 2005 but was significantly reduced in 2006 and 2007, likely due to decreased light availability during prolonged spring runoff from higher snowpacks than in 2004 and 2005. Low dissolved oxygen (<4 mg/L) occurred in 2004 and 2005 in the Kiona reach but high pH values (>9) occurred in all years and all reaches, even those without abundant plant or algal growth (Wise *et al*, 2009).

Temperature

From 2004 through 2007, a continuous water quality monitor at Kiona was deployed in the Yakima River for another study (Wise *et al*, 2009). Comparing the temperature in the river at the same 15-minute interval as RSBOJC's discrete sampling found that Spring and Snipes, located 12 miles upstream from Kiona, were cooler than the river in summer and warmer than the river in winter (figure 31); the median and 90th percentile differences were 1.4 and 3.6 deg C in Spring and 1.2 and 3.8 degrees in Snipes. In this 12-mile stretch of the Yakima River, water temperatures in late summer 2008 were found to be generally homongenous: differences between left and right transects were typically less than 0.5 ºC, differences between near-surface and near-bed temperatures were negligible, and differences between a stationary probe at Kiona and a probe pulled longitudinally through the river were typically less than 0.5 ºC (Marcella Appel, Benton Conservation District, unpublished data, 2008). Thus, the Kiona temperatures could be used with confidence to indicate river temperatures nearer to the mouth of Spring/Snipes.

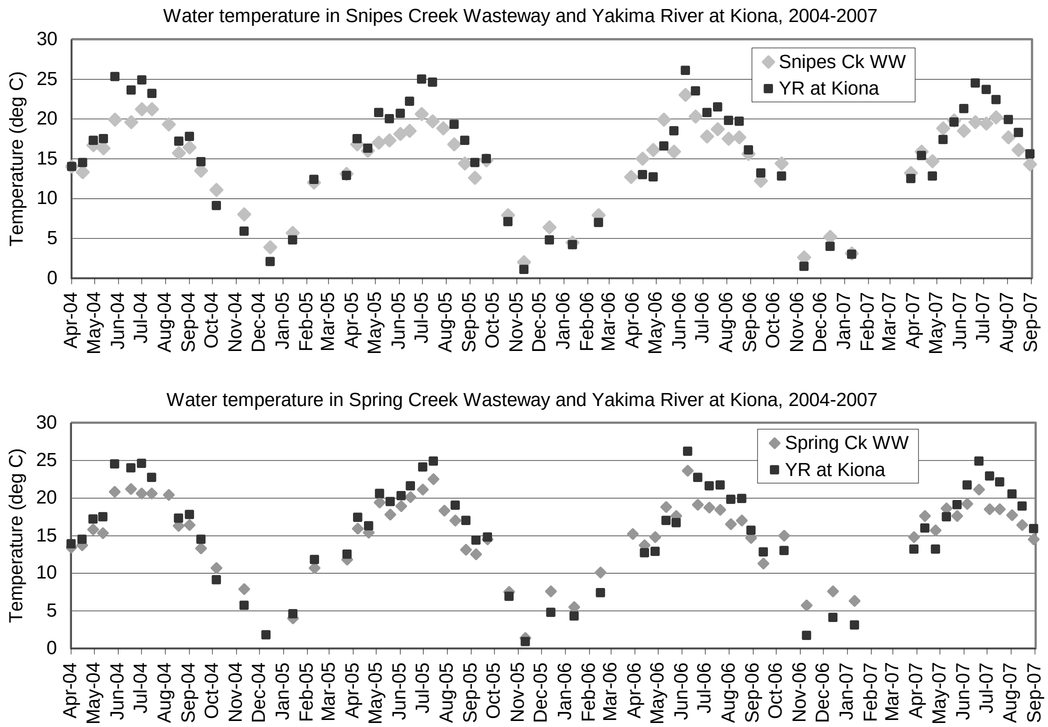


Figure 31. Concurrent instantaneous water temperatures in Spring or Snipes and the Yakima River, 2004 to 2007.

The influence of the temperature of the waterways on the Yakima River was estimated by calculating the temperature flux (temperature times discharge) for each waterbody, then calculating the percent flux contributed by the cumulative load from the waterways compared to flux load in the Yakima River. Over all four years, the median and 90th percentile values were 1.6 and 4.1%.

Discussion

Changes over time

Decreases in irrigation season concentrations of most constituents from 1997 to 2007/08 were significant as measured by percent changes in most waterways and by downward trends in all four waterways. The substantial declines in concentrations resulted in: (a) significantly decreased loads entering the lower Yakima River of almost all constituents from all four drains, which likely influenced the river to different degrees, (b) an increased importance of non-irrigation season loads to the yearly contribution of total suspended solids and total phosphorus to the river, (c) changes in monthly patterns in concentrations of several constituents, and (d) yields of total suspended solids decreased to become similar to other watersheds and less than soil loss tolerance values.

Nearly all load reductions from all four waterways between 1997 and 2008 were meaningful (greater than the uncertainty in the data) and many were substantial (51 to 97%). Load reductions in total suspended solids from the four waterways between 1997

and 2007 were similar in pattern to reductions between years in turbidity values and total suspended solids load in the river. In contrast, load reductions in total phosphorus from the waterways did not follow the same temporal pattern as total phosphorus concentrations or loads in the river. Possible reasons include (1) the load of total phosphorus from the waterways was a much smaller proportion of the load in the river than was total suspended solids and (2) phosphorus would be expected to be subject to more complex transport and fate processes than suspended solids.

In 1997, all loads except nitrate+nitrite were predominantly from the irrigation season. By 2007, after decreases in concentrations and discharge during the irrigation season, in some waterways for particulate constituents, the non-irrigation season loads were a substantial portion of the yearly load. Similarly, after the rapid decline in concentrations from 1997 to 1999, monthly patterns of concentrations changed (variably, by constituent and by waterway). In general, patterns of total suspended solids and total phosphorus concentrations changed the most, becoming comparable in most of the non-irrigation season months to most of the irrigation season months. The consequence to the river of changes in seasonal patterns of concentrations and loads is unknown.

Orders-of-magnitude decreases in yields of suspended solids since 1976 in Sulphur brought yields into the mid- and lower range of values reported in other watersheds in the arid West. Yields (on a drainage area basis, not on a field level) were less than soil tolerances for major soil types – a significant improvement from the mid-1980's, when over 90,000 acres in the Yakima Basin were considered to have exceeded their soil loss tolerance (Dawson and Domka, 1987 as cited in US Dept of Interior, Sept. 2008). In contrast, nutrient yields from Granger and Sulphur were generally high compared to other watersheds and in the mid or lower range for Spring and Snipes. In a few later years, estimated annual yields of total phosphorus during the non-irrigation seasons in Spring and Snipes were slightly less than phosphorus yields from undeveloped basins throughout the U.S. – remarkable in an irrigated area.

The high concentrations of 1997 to 2000 were not anomalous, generally falling within the range of historical data from 1974 to 1981. Thus, the lower concentrations of most constituents from 2000 to 2008 marked a meaningful change, not an artifact of unusually high concentrations in the early years of monitoring.

Increasing nitrate+nitrite trends in all four waterways were likely due, at least in part, to decreasing discharge -- as the proportion of return flows and canal spills decreased, the proportion of groundwater increased.

Only total Kjeldahl nitrogen did not show a trend in all four waterways – it was downward only in Granger. Also unlike the other constituents, total Kjeldahl nitrogen concentrations were similar during the irrigation and non-irrigation seasons, except in Sulphur where non-irrigation season concentrations were greater than the irrigation season. These differences suggest that total Kjeldahl nitrogen concentrations were primarily responding to influences other than irrigation-induced erosion.

During the non-irrigation seasons, only half of the analyses showed trends; the number of upward and downward trends were nearly the same. Changes in any given constituent were inconsistent between waterways.

Factors influencing water quality
Changes over time during the irrigation season could best be explained by changes in on-farm irrigation water management and water availability.

Irrigation-induced erosion is the dominant process moving particles from the land surface to surface waters during the irrigation season in these drainage areas. The sheer magnitude of the decreased concentrations from 1997 to 2000 and that decreases occurred in all four waterways strongly suggest on-farm irrigation management practices were primarily responsible. Changes in crop types over time were not assessed within these drainages but were unlikely to have been consistent between drainage areas. Precipitation and air temperature data were assessed and did not correspond to the observed changes in water quality. Major changes in canal operations or drain maintenance did not occur from 1997 to 2000.

Despite the well-known and well-documented relationship between irrigation practices and surface water quality, the implementation rate of partially publicly-funded irrigation improvements did not directly relate to the rate of total suspended solids concentration reductions between years.

In response to decreased water supplies during two drought years and after a re-regulation reservoir was installed to improve the efficiency of the Sunnyside Canal, total suspended solids concentrations decreased, nitrate+nitrite concentrations increased, and fecal coliform concentrations remained similar. During drought years, concentrations of total Kjeldahl nitrogen and total phosphorus remained comparable to non-drought years, unlike after the re-regulation reservoir, when concentrations of total Kjeldahl nitrogen increased and total phosphorus decreased or remained similar. Increased nitrate+nitrite concentrations were likely the result of decreased dilution from canal spill water. The reason total Kjeldahl nitrogen increased after the re-regulation reservoir but remained comparable during drought years is unknown. Decreased total suspended solids concentrations during drought years were likely a result of decreased turbidity and quantity of on-farm run-off, but in the years after the re-regulation reservoir were likely a result of less in-channel movement of deposited materials -- water velocities would have slowed considerably when median discharge decreased from 47 cfs before the reservoir to 17 cfs after the reservoir. Median discharge and total dissolved solids yields in Spring after the re-regulation reservoir became comparable to Granger, which also does not receive canal spill water.

No known changes over time in drainage area conditions corresponded to the changes in water quality during the non-irrigation season.

Regulatory considerations
Despite high water temperatures in the summer which exceeded state standards, Spring and Snipes were cooler than river, providing cool-water refugia in the river near their combined

outlet on a micro-habitat scale but not on a reach scale. Dissolved oxygen was most often less than 8 mg/L in July and August. Unexpectedly, pH values exceeded 8.5 more often in winter than summer (perhaps a function of differing sampling frequency or dilution from canal water), suggesting limits on the ability of these waterways to meet state standards during warmer summer months. The state fecal coliform criteria (geometric mean and top-10-percent) were not met in any year by any waterway – even in Spring and Snipes with the lowest proportion of irrigated acres, the highest proportion of drip irrigation, and the highest proportion of orchards and vineyards.

Differences between drainage areas

Factors such as crop type, irrigation type, soils, and slopes were expected to relate to water quality conditions based on other studies and current management practices. For example, in the Columbia Basin, suspended sediment yields decreased in sprinkler-dominated areas compared to furrow-dominated areas (Ebbert and Moon, 1998). Slope best explained variability in total suspended solids yield between Sulphur sub-basins (Boucher and Fretwell) and corresponded to a higher percentage of samples from the Yakima Basin exceeding a settable solids criteria (Ecology, 1982). Based on the composition of manure, one might expect higher nitrogen, phosphorus, and fecal coliform yields in drainages with higher proportions of cows. While dairies are required by state law, RCW 90.64, to develop nutrient management plans which balance the amount of nitrogen in manure applied as fertilizer against the agronomic needs of the crop grown each year, off-site users of manure are not required to do so, nor are phosphorus application rates required to be balanced against agronomic rates.

Differences in water quality conditions between these four drainage areas during the irrigation season, however, did not generally correspond to differences in crop and irrigation types, slope, or soils. Spring and Snipes had more permanent crops, fewer dairies, a larger percentage of drip irrigation, and steeper slopes than Granger and Sulphur. Yet yields of total suspended solids, total phosphorus, and total Kjeldahl nitrogen during the irrigation season were comparable in Granger and Spring. Yields of fecal coliform were comparable in Granger and Spring, highest in Sulphur, and lowest in Snipes.

Within Sulphur and Granger, slopes were similar, soils were more erodible in Sulphur but tend to stay in suspension longer in Granger, Sulphur had more grapes and Granger had more corn, and Granger had more acres owned by dairies than Sulphur. Yet irrigation season concentrations of total suspended solids, fecal coliform and total Kjeldahl nitrogen were comparable between Sulphur and Granger sub-basins. Nitrate+nitrite concentrations were higher and total phosphorus concentrations were lower in Sulphur sub-drains than in Granger sub-drains. The influence of the Sunnyside urban area increased concentrations of total phosphorus, total Kjeldahl nitrogen, and fecal coliform in Sulphur Creek Wasteway as indicated by increasing concentrations and yields between a site upstream and downstream of the urban area.

During the non-irrigation season, the primary known transport mechanisms are (a) stormwater runoff, (b) bedload movement within the waterways, and (c) groundwater seeping into the waterways. These factors in combination may help explain why yields of

water and most constituents in Spring and Snipes were substantially lower than in Granger and Sulphur. (a) The potential influence of stormwater was likely largest in Sulphur and Granger, with urban areas of about 4,500 and 500 acres, respectively, and no urban areas in Spring or Snipes. (b) The dominant drain substrates were fines in Sulphur and Granger and gravel and cobble in Spring and Snipes, which would allow bedload movement at lower water velocities in Sulphur and Granger than in Spring or Snipes. (c) Spring and Snipes had more surficial basalt than Granger or Sulphur, possibly decreasing the connectivity of the drain to shallow groundwater. Snipes also had the lowest proportion of irrigated acres within its drainage area, likely responsible at least in part for it having the smallest ratio of irrigation-to-non-irrigation median discharge values. Nitrate+nitrite loads were similar year-round in Sulphur, Granger, and Spring but not in Snipes where they decreased during the non-irrigation season -- another possible indicator of less connectedness between groundwater and surface water in Snipes.

Elevated nitrate+nitrite concentrations at site 23 in Granger and site 25.3 in Sulphur, in comparison to other sites, may be related to the depths of the drains at those sites (both appear unusually deep) but insufficient information was available to systematically compare depths at other sites.

When comparing the total suspended solids load delivered to these drainage basins in canal water during the 2000 and 2004 irrigation seasons against the load in the waterways, it was estimated that in Spring/Snipes more load entered the basin than left the basin while in Granger and Sulphur more load left the basins than entered. If this roughly estimated mass balance is later determined to be accurate using other methods, the net gain of total suspended solids in the Spring/Snipes drainage areas could be a quantifiable indicator of successful conservation practices.

Complicating factors

The complexity of these systems cannot be overstated. The following examples illustrate just three sources of complexity.

Substantial deposition of particulate constituents occurred during the non-irrigation seasons in Sulphur (i.e., nine tons per day of total suspended solids) which would likely be resuspended when water velocity increases at the beginning of an irrigation season, unless the deposited material had been removed by periodic drain maintenance activities.

Age-dating of groundwater in one Granger sub-basin found ages of less than two years old to greater than 60 years old (Hank Johnson, USGS, personal communication, July 2005). In addition to complex hydrogeological flowpaths, crop type can influence the age of groundwater in irrigated areas. The desethylatrazine-to-atrazine ratio was significantly higher in orchard than row crop areas in the Columbia Basin, indicating longer groundwater residence times (Jones and Roberts, 1998). In DR2 in Granger, nitrate in groundwater was partially removed as it entered the surface drain, but once within the channel, streambed denitrification was not an efficient nitrate sink due to very low transient storage times resulting from the engineered geomorphology (low gradient and fine-grained

sediments) (Duff *et al*, 2008). Spring and Snipes have higher gradients and larger-sized substrate and thus may be more efficient nitrate sinks.

Finally, current known values for water delivery rates, crop consumption needs, and discharge yields in these drainage areas did not balance. In 2004, the average estimated amount delivered to farms was 2.6 ac-ft/ac for Roza and 3.1 ac-ft/ac for Sunnyside. The average consumptive use of major crops in the area was 3 ac-ft/ac. On-farm irrigation system efficiencies are typically 65-90% (USDA, 1997), meaning that it is necessary to apply 3.3-5.0 ac-ft/ac for the crop to receive 3 ac-ft/ac. Recent modeled estimates of actual evapotranspiration losses for the Roza-Sunnyside and Toppenish areas were 28.3 and 26.7 inches (2.4 and 2.2 feet) per acre per year, respectively (Vaccaro and Olsen, 2007). Discharge yields from Granger and sub-drains in Sulphur which do not receive canal spill water were often roughly one ac-ft/acre. The imbalance between water delivery rates, the amount needed by the crops, and discharge yield could be due to the inherent problems in using averages, uncertainty in the data (delivery rates, on-farm efficiencies, or evapotranspiration rates), or perhaps a reflection of temporal discontinuities (this year's discharge may not reflect this year's irrigation rate due to varying transit times of water through soil).

The interconnectedness between irrigation and non-irrigation seasons, the complex and difficult-to-quantify nutrient transport processes, and the water imbalance all may have contributed to the difficulty in relating drainage area characteristics to water quality conditions and quantitatively relating changes over time to irrigation improvements. Yet other studies have found relationships. Perhaps more precise or more powerful analysis tools, drainage-specific details for Spring and Snipes, and other details (such as the percentage of bare ground during winter) are needed to better quantify relationships.

Conclusions

Water quality conditions significantly improved in four major irrigation waterways from 1997 to 2008. Substantial declines in concentrations of several constituents during the irrigation seasons resulted in: (a) significantly decreased loads entering the lower Yakima River of almost all constituents from all four drains which likely influenced the river to different degrees, (b) an increased importance of non-irrigation season loads to the yearly contribution of total suspended solids and total phosphorus to the river, (c) changes in monthly patterns in concentrations of several constituents, and (d) yields of total suspended solids decreased to become similar to other watersheds and less than soil loss tolerance values.

Total Kjeldahl nitrogen concentrations may have been primarily influenced by unknown factors other than irrigation-induced erosion. Increasing nitrate+nitrite concentrations between years during the non-irrigation seasons were likely in response, at least in part, to decreasing discharge values.

Decreased concentrations and loads in all four waterways from 1997 to 2008 could best be explained by improved irrigation practices, especially for the substantial declines from 1997 to 2000. The varying rate of water quality improvements did not follow the same

pattern as varying rates of participation in $20,067,033 of publicly-funded programs which assisted growers to improve irrigation practices on roughly 34,700 acres.

In a few years, drought and improved canal efficiency decreased concentrations of total suspended solids (likely due to decreased run-off from farms and decreased in-channel movement of deposited materials, respectively) and increased concentrations of nitrate+nitrite due to less dilution from surface waters. The reasons that fecal coliform, total phosphorus, and total Kjeldahl nitrogen concentrations remained comparable between years or responded differently to drought versus canal efficiency improvements are unknown.

The waterway with the lowest concentrations, loads, and yields of most constituents, Snipes Creek Wasteway, failed to consistently meet state water quality criteria during the irrigation season, one indication of the level of difficulty in reaching compliance in the other waterways. But perhaps conditions in Snipes may be useful as a yardstick against which to measure potential progress in the other waterways.

Reductions in total phosphorus loads from the waterways did not correspond to the pattern of decreased phosphorus concentrations or loads in the Yakima River at Kiona, although both generally declined in the river over time. Reductions in total suspended solids load from the waterways were similar to reductions in the river. Substantial reductions in fecal coliform concentrations did not achieve compliance with state standards in the waterways but the river at Kiona met state criteria from 2000 to 2008.

Differences in yields between drainage areas during the irrigation season did not correspond as expected to differences in drainage area characteristics. Differences in yield between drainage areas during the non-irrigation seasons may have been related to differences in land use (urban vs. rural), type of drain substrate, surficial geology, and proportion of the drainage area under irrigation.

Future efforts to improve water quality may benefit from a better understanding of the factors which result in generally better water quality in Spring and Snipes, the factors influencing spatial variability in nutrient concentrations, the influence of changing crops over the years, ways to minimize the effects of the urban area, variability in on-farm irrigation water application rates, and the relationship between irrigation and non-irrigation season conditions.

Glossary

Canal. A man-made conveyance structure that delivers supply water from the Yakima River. Canals convey water to laterals. Irrigation deliveries may also be drawn directly from the canal.

Concentration. The amount of material in a water sample on a per volume basis, such as milligrams per liter.

Discharge. Rate of water flow, often in cubic feet per second (cfs).

Drain. A man-made conveyance ditch or pipe that primarily functions to lower the groundwater table and conveys this water to the river. Drains usually also act as wasteways.

E. coli or ***Escherichia coli.*** An aerobic and facultative gram negative nonspore forming rod shaped bacterium that can grow at 44.5 degrees Celsius that is ortho-nitrophenyl-B-D-galactopyranoside (ONPG) positive and Methylumbelliferyl glucuronide (MUG) positive.

Eutrophication. The process of nutrient-enrichment, resulting in high primary productivity rates often accompanied by frequent oxygen depletion and high pH values.

Evapotranspiration. The sum of evaporation and plant transpiration. Evaporation is the movement of water to the air from sources such as the soil, canopy interception, and waterbodies. Transpiration is the movement of water within a plant and subsequent loss of water as vapor through stomata in its leaves.

Fecal coliform. Bacteria from the gut of warm-blooded animals, used to indicate the potential presence of pathogens. Specifically, that portion of the coliform group which is present in the intestinal tracts and feces of warm-blooded animals as detected by the product of acid or gas from lactose in a suitable culture medium within twenty-four hours at 44.5 plus or minus 0.2 degrees Celsius. Often measured in colonies per 100 milliliters of water (col/100 mL).

Geometric mean. An indication of the central tendancy of a set of numbers. Similar to the mean, except that instead of adding the set of numbers and then dividing the sum by the count of numbers in the set, *n*, the numbers are multiplied and then the n^{th} root of the resulting product is taken.

JD or Joint Drain. A drain system for which the Roza Irrigation District and the Sunnyside Valley Irrigation District have operation and maintenance responsibilities which is formalized through contract.

Laterals. Ditches that convey water to farm delivery structures.

Load. The mass of substance (constituent) being discharged from a source, often calculated on a daily basis, such as pounds per day of phosphorus.

Mean. A measure of central tendency. A set of numbers is added together, then their sum is divided by the count of numbers in the set, *n*.

Median. A measure of central tendency. The value for which half of the values are smaller and half of the values are larger. Less distorted by extreme values than the mean.

Nitrate+nitrite. Nitrogen in oxidized (nitrate) and reduced (nitrite) forms, as nitrogen (mg/L).

Percentile. The fraction of data equal to or less than the percentile value. For example, the 25^{th} percentile is the point at which 25 percent of the data are equal or less than the stated value.

pH. The negative logarithm of the hydrogen ion concentration. A measure of acidity or basicity (alkalinity) of a solution.

Specific conductance. Ability of water to carry an electrical current, expressed in microsiemens per centimeter (uS/cm). Siemens are the reciprocal of ohms.

Tailwater. Irrigation water collected at the bottom end ('tail') of a field, which is then usually returned to irrigation drains.

Tile drainage. Usually refers to subsurface perforated pipes installed in fields to collect drainage water and convey it off-site to a larger pipe or drain.

TMDL. Total maximum daily load, the amount (load) of a contaminant a body of water is able to receive without resulting in exceedances of state water quality criteria. Also called a water quality clean-up plan.

Total dissolved solids. Dissolved ions usually as salts (mg/L).

Total Kjeldahl nitrogen. Organic nitrogen plus ammonia, as nitrogen (mg/L). Nitrogen in the form of organic proteins or their decomposition product ammonia. Sources include fertilizer, the decay of organic material such as plant material and animal wastes, and sewage and organic waste.

Total phosphorus. Dissolved and sediment-bound phosphorus (mg/L), both organic and inorganic forms.

Total suspended solids. Sediment suspended in water, measured in milligrams per liter (mg/L), which is equivalent to parts-per-million (ppm).

Wasteway. A man-made conveyance structure that primarily conveys canal, lateral, and landowner operational spill and tailwater to the river. Operational spill is both routine spilled canal water that optimizes canal flow for delivery and emergency spilled canal water to a wasteway due to leaks, failures, and for required repairs. Major wasteways are designed and constructed to divert the entire canal flow in emergency and operational cases. Wasteways usually also act as drains.

Drains and wasteways constructed in upland (ephemeral before irrigation) areas are generally defined as irrigation ditches under the US Army Corps of Engineers regulatory guidance letter No. 07-02 for the purpose of determining permit exemptions under Section 404 of the Clean Water Act.

Yield. The pounds per acre per day of a given constituent from a drainage area, or in the case of discharge, the volume of water per acre per day from a drainage area. Yield is useful because it eliminates differences in loads solely due to differences in drainage size.

Units

ac-ft	Acre-feet.
ac-ft/ac	Acre-feet per acre.
cfs	Cubic feet per second.
col/sec	Colonies per second.
col/sec/ac	Colonies per second per acre.
col/100 mL	Colonies per 100 milliliters; equivalent to col/dl (colonies per deciliter)
dL	Deciliter (equals 100 milliliters).
deg C	Degrees Celcius.
deg F	Degress Fahrenheit.
lb/day	Pounds per day.
lb/ac/day	Pounds per acre per day.
mg/L	Milligrams per liter.
NTU	Nephelometric turbidity unit.
ppm	Part per million.
ug/L	Micrograms per liter.
uS/cm	Microsiemens per centimeter.

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Appendix

Table of concentrations, loads, and yields: medians and other values.

Irrigation Seasons (April 1 through October 18)										
Concentrations and values (medians unless otherwise noted)										
	Granger	Sulphur	Spring	Snipes			Granger	Sulphur	Spring	Snipes
90th percentile turbidity (NTU)						*Median total suspended solids (mg/L)*				
1997	284	82	50	24		1997	353	221	118	41
1998	125	60	49	27		1998	300	96	67	35
1999	136	54	45	20		1999	264	97	80	19
2000	45	18	25	15		2000	109	49	43	17
2001	46	15	14	9		2001	50	13	28	6
2002	61	22	26	11		2002	101	35	33	10
2003	47	16	22	6		2003	62	27	36	4
2004	47	15	21	11		2004	77	25	34	10
2005	30	17	19	10		2005	35	28	24	4
2006	69	27	23	19		2006	126	26	7	7
2007	54	20	16	22		2007	23	19	9	5
2008	73	21	20	22		2008	180	23	11	14
Geometric mean fecal coliform (col/100 mL)						*Top-10% fecal coliform (col/100 mL)*				
1997	1,419	1,500	670	104		1997	5,600	3,300	2,500	390
1998	1,111	1,059	504	238		1998	2,500	2,100	980	610
1999	1,351	800	371	91		1999	3,400	2,000	5,100	900
2000	781	457	231	61		2000	3,200	6,100	1,300	670
2001	581	361	230	107		2001	1,500	510	1,200	2,000
2002	447	410	170	98		2002	1,800	1,200	540	370
2003	366	285	182	41		2003	690	720	400	300
2004	374	353	128	37		2004	1,100	790	850	400
2005	306	369	228	114		2005	1,800	770	1,100	450
2006	1,050	593	265	122		2006	3,300	1,600	2,800	560
2007	597	643	226	82		2007	2,600	3,800	1,700	2,100
2008	482	402	209	76		2008	1,387	1,700	710	2,900
Median nitrate+nitrite (mg/L)						*Median total phosphorus (mg/L)*				
1997	2.66	2.27	1.20	0.54		1997	0.817	0.357	0.216	0.090
1998	2.38	2.36	0.89	0.50		1998	0.530	0.230	0.130	0.085
1999	2.06	1.81	0.60	0.39		1999	0.500	0.191	0.140	0.078
2000	2.33	1.48	0.70	0.32		2000	0.250	0.123	0.103	0.069
2001	2.89	3.27	0.75	0.59		2001	0.220	0.155	0.075	0.067
2002	2.18	3.27	0.76	0.40		2002	0.250	0.155	0.079	0.059
2003	2.23	1.76	0.80	0.75		2003	0.205	0.116	0.082	0.058
2004	2.40	2.25	0.99	0.60		2004	0.245	0.120	0.094	0.069
2005	2.78	2.31	0.77	0.68		2005	0.200	0.131	0.091	0.074
2006	2.74	2.97	1.57	0.68		2006	0.310	0.148	0.069	0.066
2007	2.73	2.31	1.35	0.51		2007	0.205	0.135	0.070	0.059
2008	2.79	2.24	2.00	0.53		2008	0.340	0.166	0.1	0.095
Median total Kjeldahl nitrogen (mg/L)						*Median discharge (mg/L)*				
1997	1.18	0.63	0.38	0.26		1997	63	331	55	51
1998	0.63	0.46	0.31	0.26		1998	56	246	45	39
1999	0.54	0.42	0.32	0.27		1999	59	355	50	41
2000	0.35	0.30	0.26	0.22		2000	60	352	48	31.4
2001	0.38	0.37	0.25	0.26		2001	31	102	39	4
2002	0.41	0.31	0.28	0.21		2002	52	268	44	24
2003	0.39	0.36	0.31	0.24		2003	51	201	53	11
2004	0.42	0.39	0.30	0.27		2004	50	220	45	16
2005	0.34	0.46	0.29	0.23		2005	28	155	27	5
2006	0.48	0.41	0.36	0.27		2006	49	192	16	13
2007	0.41	0.33	0.33	0.25		2007	49	313	17	15
2008	0.60	0.36	0.43	0.30		2008	52	160	14	30.8

Irrigation season concentrations and values, continued										
	Granger	Sulphur	Spring	Snipes			Granger	Sulphur	Spring	Snipes
Median total dissolved solids (mg/L)						*Ratio of median non-irrigation instantaneous discharge to irrigation instantaneous discharge*				
1997	256	179	149	118		1997	0.41	0.21	0.09	0.03
1998	229	169	136	124		1998	0.41	0.28	0.07	0.03
1999	216	158	116	107		1999	0.41	0.17	0.07	0.02
2000	224	141	116	108		2000	0.41	0.16	0.11	0.03
2001	270	238	117	224		2001	0.64	0.49	0.08	0.09
2002	215	161	118	142		2002	0.45	0.21	0.10	0.05
2003	217	184	123	205		2003	0.46	0.31	0.12	0.15
2004	226	182	147	164		2004	0.45	0.26	0.08	0.08
2005	263	218	118	203		2005	0.75	0.37	0.18	0.15
2006	237	201	216	184		2006	0.43	0.27	0.32	0.15
2007	242	180	206	162		2007	0.48	0.22	0.34	0.09
2008	221	183	216	153						
Instantaneous Loads and Seasonal Discharge										
	Granger	Sulphur	Spring	Snipes			Granger	Sulphur	Spring	Snipes
Median total suspended solids (lb/day)						*Median total phosphorus (lb/day)*				
1997	129,839	342,495	28,372	8,123		1997	283	581	45	23
1998	81,968	172,366	13,615	7,964		1998	150	349	35	18
1999	87,864	250,643	18,784	3,833		1999	167	371	35	15
2000	31,189	87,081	10,214	2,241		2000	68	211	31	10
2001	9,521	7,422	5,162	80		2001	37	86	14	1
2002	28,864	46,396	6,446	1,373		2002	73	166	18	7
2003	16,432	26,621	11,478	221		2003	60	117	22	4
2004	25,733	33,957	8,374	501		2004	71	154	19	6
2005	4,382	19,801	4,218	121		2005	30	111	13	3
2006	29,572	20,092	419	585		2006	57	131	6	5
2007	5,941	41,968	1,020	229		2007	53	258	7	6
2008	50,806	14,987	786	2,444		2008	98	165	7	13
Median nitrate+nitrite (lb/day)						*Median total Kjeldahl nitrogen (lb/day)*				
1997	847	4,163	311	138		1997	388	856	74	62
1998	705	3,178	212	88		1998	182	704	75	58
1999	636	3,122	168	88		1999	190	794	81	46
2000	745	2,703	178	44		2000	107	556	69	37
2001	507	1,738	127	11		2001	60	213	42	4
2002	563	2,324	169	34		2002	117	420	55	26
2003	640	2,189	242	35		2003	112	383	84	12
2004	669	2,657	224	54		2004	110	432	67	21
2005	421	2,201	108	27		2005	51	404	40	12
2006	645	2,396	142	41		2006	103	454	23	18
2007	702	3,388	151	56		2007	108	598	32	26
2008	797	1,823	152	63		2008	163	355	28	46
Median fecal coliform (col/sec)						*Median total dissolved solids (tons/day)*				
1997	25,566,992	137,504,928	7,616,322	1,544,339		1997	42	155	20	15
1998	16,712,192	94,028,064	7,957,355	2,636,070		1998	34	128	15	13
1999	26,786,755	68,194,560	4,726,905	827,538		1999	34	143	16	12
2000	12,558,872	38,000,909	2,924,054	548,769		2000	35	127	16	10
2001	4,998,324	11,001,697	1,300,839	100,932		2001	24	65	12	2
2002	6,178,461	28,847,885	1,981,947	516,914		2002	30	115	14	8
2003	5,310,805	16,969,344	3,190,248	177,543		2003	30	103	17	6
2004	5,169,575	22,541,389	1,353,345	87,546		2004	31	107	17	8
2005	2,387,006	12,847,425	1,761,277	175,103		2005	19	87	11	3
2006	13,542,624	28,153,478	931,728	549,691		2006	30	95	10	7
2007	7,266,632	48,242,554	1,525,032	351,259		2007	31	137	10	8
2008	7,650,790	21,081,635	869,719	356,526		2008	31	77	9	10

Yields

	Granger	Sulphur	Spring	Snipes			Granger	Sulphur	Spring	Snipes
Median total suspended solids (lb/ac/day)						*Median total phosphorus (lb/ac/day)*				
1997	5.4	9.6	2.6	1.4		1997	0.012	0.016	0.004	0.004
1998	3.4	4.9	1.2	1.4		1998	0.006	0.010	0.003	0.003
1999	3.6	7.1	1.7	0.7		1999	0.007	0.010	0.003	0.003
2000	1.3	2.5	0.9	0.4		2000	0.003	0.006	0.003	0.002
2001	0.4	0.2	0.5	0.01		2001	0.002	0.002	0.001	0.000
2002	1.2	1.3	0.6	0.2		2002	0.003	0.005	0.002	0.001
2003	0.7	0.7	1.1	0.0		2003	0.002	0.003	0.002	0.001
2004	1.1	1.0	0.8	0.1		2004	0.003	0.004	0.002	0.001
2005	0.2	0.6	0.1	0.02		2005	0.001	0.003	0.001	0.001
2006	1.2	0.6	0.0	0.1		2006	0.002	0.004	0.001	0.001
2007	0.2	1.2	0.1	0.04		2007	0.002	0.007	0.001	0.001
2008	2.1	0.4	0.1	0.4		2008	0.004	0.005	0.001	0.002
Median nitrate+nitrite (lb/ac/day)						*Median total Kjeldahl nitrogen (lb/ac/day)*				
1997	0.032	0.08	0.028	0.025		1997	0.016	0.02	0.007	0.011
1998	0.027	0.06	0.019	0.016		1998	0.008	0.02	0.007	0.010
1999	0.024	0.06	0.015	0.016		1999	0.008	0.02	0.007	0.008
2000	0.029	0.05	0.016	0.008		2000	0.004	0.02	0.006	0.007
2001	0.019	0.03	0.012	0.002		2001	0.002	0.01	0.004	0.001
2002	0.022	0.05	0.015	0.006		2002	0.005	0.01	0.005	0.005
2003	0.025	0.04	0.022	0.006		2003	0.005	0.01	0.008	0.002
2004	0.026	0.05	0.021	0.010		2004	0.005	0.01	0.006	0.004
2005	0.016	0.04	0.010	0.005		2005	0.002	0.01	0.004	0.002
2006	0.025	0.05	0.013	0.007		2006	0.004	0.01	0.002	0.003
2007	0.027	0.07	0.012	0.010		2007	0.004	0.02	0.003	0.005
2008	0.031	0.04	0.014	0.011		2008	0.007	0.01	0.003	0.008
Median fecal coliform (col/sec/ac)						*Median total dissolved solids (lb/ac/day)*				
1997	1,058	3,871	698	275		1997	3.3	6.2	3.6	5.2
1998	692	2,647	729	469		1998	2.6	5.1	2.8	4.7
1999	1,109	1,920	433	147		1999	2.6	5.7	2.9	4.4
2000	520	1,070	238	18		2000	2.7	5.1	2.9	3.6
2001	207	310	100	14		2001	1.8	2.6	2.1	0.6
2002	256	812	182	17		2002	2.3	4.6	2.5	2.9
2003	220	478	292	32		2003	2.3	4.1	3.1	2.0
2004	214	635	124	16		2004	2.4	4.3	3.1	2.7
2005	102	362	161	43		2005	1.4	3.5	2.1	1.1
2006	555	792	85	98		2006	2.3	3.8	1.8	2.4
2007	301	1,358	131	60		2007	2.4	5.5	1.7	2.9
2008	317	593	80	63		2008	2.4	3.1	1.6	3.4
Median seasonal discharge (ac-ft/ac/200 days)										
1997	1.0	2.6	1.7	3.6						
1998	0.9	2.0	1.6	2.8						
1999	0.9	2.8	1.8	2.9						
2000	0.9	2.8	1.7	2.2						
2001	0.5	0.8	1.4	0.3						
2002	0.8	2.1	1.6	1.7						
2003	0.8	1.6	2.0	0.8						
2004	0.8	1.7	1.6	1.2						
2005	0.4	1.2	1.0	0.4						
2006	0.7	1.5	0.6	0.9						
2007	0.8	2.5	0.6	1.1						
2008	0.8	1.3	0.5	2.2						

Non-irrigation Seasons (October 19 through March 30)										
Concentrations and values (medians unless otherwise noted)										
	Granger	Sulphur	Spring	Snipes			Granger	Sulphur	Spring	Snipes
90th Percentile Turbidity						*Median total suspended solids (mg/L)*				
1997	58	48	6	3		1997	80	29	3	2
1998	29	15	6	3		1998	73	13	1	1
1999	23	14	5	3		1999	48	22	4	3
2000	44	35	8	3		2000	49	25	5	3
2001	25	19	3	7		2001	35	22	3	4
2002	34	34	4	2		2002	73	53	3	1
2003	30	44	7	2		2003	42	38	2	1
2004	24	44	4	4		2004	48	21	3	1
2005	41	65	16	3		2005	61	67	2	0
2006	42	28	19	18		2006	93	32	2	1
2007	40	35	6	2		2007	50	43	2	0
Geometric mean fecal coliform (col/100 mL)						*Top-10% fecal coliform (col/100 mL)*				
1997	1,248	461	709	15		1997	4,200	1,600	3,800	67
1998	283	329	673	24		1998	2,000	1,000	1,900	130
1999	193	278	475	11		1999	530	790	1,600	170
2000	165	383	94	17		2000	260	900	180	28
2001	209	333	46	17		2001	1,700	420	310	60
2002	87	355	96	7		2002	320	430	310	44
2003	70	329	180	26		2003	240	470	1,400	82
2004	57	314	32	24		2004	210	530	66	22
2005	121	632	53	14		2005	1,400	1,300	660	71
2006	160	1,139	69	13		2006	730	6,900	140	16
2007	55	580	41	17		2007	180	2,100	330	60
Median nitrate+nitrite (mg/L)						*Median total phosphorus (mg/L)*				
1997	6.20	7.69	6.56	3.98		1997	0.360	0.256	0.087	0.100
1998	5.75	7.62	5.45	3.45		1998	0.200	0.188	0.069	0.059
1999	5.70	7.44	5.84	2.90		1999	0.180	0.192	0.071	0.068
2000	5.98	7.41	6.22	2.84		2000	0.200	0.210	0.083	0.088
2001	5.71	6.91	6.23	1.64		2001	0.159	0.196	0.065	0.083
2002	6.37	6.35	5.69	2.00		2002	0.193	0.240	0.057	0.070
2003	6.01	7.37	5.66	2.09		2003	0.172	0.199	0.070	0.061
2004	6.04	7.76	5.99	2.51		2004	0.190	0.196	0.074	0.078
2005	6.44	8.10	5.69	1.35		2005	0.210	0.280	0.064	0.083
2006	7.10	8.39	6.04	3.36		2006	0.230	0.705	0.085	0.069
2007	6.87	8.48	6.26	2.37		2007	0.170	0.490	0.069	0.050
Median total Kjeldahl nitrogen (mg/L)						*Median instantaneous discharge (cfs)*				
1997	0.90	0.73	0.37	0.36		1997	26	71	5	1.5
1998	0.38	0.56	0.27	0.26		1998	23	69	3	1.3
1999	0.40	0.56	0.26	0.27		1999	24	61	4	1.0
2000	0.36	0.66	0.34	0.22		2000	24	57	5	1.0
2001	0.28	0.79	0.29	0.16		2001	20	50	3	0.3
2002	0.42	0.80	0.28	0.20		2002	23	56	5	1.1
2003	0.37	0.82	0.35	0.24		2003	23	63	6	1.6
2004	0.46	0.60	0.27	0.21		2004	22	56	3	1.3
2005	0.52	0.93	0.29	0.21		2005	21	57	5	0.8
2006	0.48	1.28	0.40	0.33		2006	21	51	5	2.0
2007	0.55	0.68	0.31	0.26		2007	24	70	6	1.4

Non-irrigation season concentrations and values, continued

	Granger	Sulphur	Spring	Snipes
Median total dissolved solids (mg/L)				
1997	459	452	452	412
1998	460	457	454	456
1999	455	442	456	426
2000	471	458	468	386
2001	457	459	471	301
2002	454	452	437	335
2003	470	449	448	359
2004	451	445	445	306
2005	441	465	404	216
2006	452	494	430	426
2007	471	467	419	382

Instantaneous Loads and Seasonal Discharge

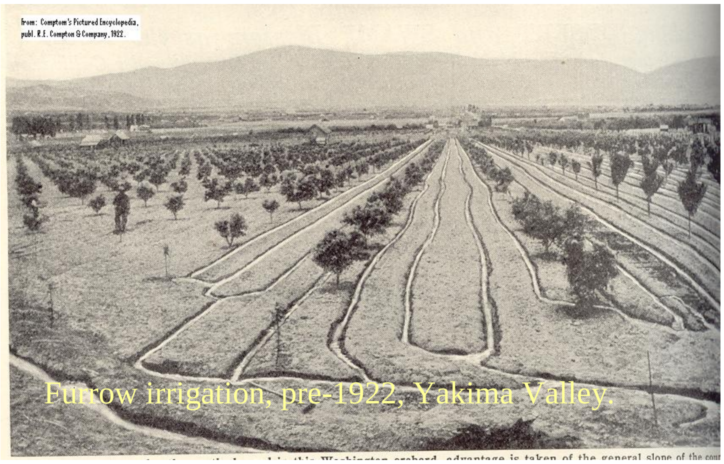
	Granger	Sulphur	Spring	Snipes		Granger	Sulphur	Spring	Snipes
Median total suspended solids (lb/day)					*Median total phosphorus (lb/day)*				
1997	11,258	13,866	116	29	1997	55	101	2.44	1.21
1998	8,220	4,602	45	5	1998	22	66	1.70	0.46
1999	6,382	8,820	99	19	1999	22	65	1.38	0.52
2000	6,717	8,102	228	17	2000	27	74	2.37	0.50
2001	3,469	6,396	47	15	2001	16	55	1.23	0.19
2002	8,985	20,335	58	8	2002	25	81	1.38	0.46
2003	5,116	15,690	33	7	2003	21	74	2.22	0.64
2004	5,863	15,819	29	7	2004	23	68	1.46	0.38
2005	6,450	31,092	113	5	2005	19	86	2.02	0.51
2006	9,197	15,014	89	8	2006	26	189	2.76	0.81
2007	6,321	20,187	54	4	2007	22	188	1.81	0.11
Median nitrate+nitrite (lb/day)					*Median total Kjeldahl nitrogen (lb/day)*				
1997	942	3,037	130	33	1997	137	342	9	4
1998	690	2,725	93	26	1998	43	211	5	2
1999	743	2,541	130	18	1999	55	207	4	2
2000	835	2,334	192	17	2000	50	199	8	1
2001	584	1,886	98	3	2001	28	212	4	0
2002	804	2,295	138	14	2002	52	244	7	1
2003	724	2,496	124	17	2003	45	309	7	2
2004	732	2,417	116	8	2004	56	234	6	1
2005	712	2,321	140	9	2005	42	296	9	1
2006	771	2,335	176	31	2006	48	347	16	3
2007	882	3,233	205	7	2007	71	264	11	2
Median fecal coliform (col/sec)					*Median total dissolved solids (tons/day)*				
1997	10,052,128	12,302,208	890,381	1,835	1997	33.5	86.5	6.6	1.3
1998	1,868,025	5,272,957	551,985	10,467	1998	28.6	83.9	3.6	1.7
1999	1,226,254	6,183,049	459,462	4,860	1999	30.2	76.4	4.4	1.2
2000	1,744,660	6,105,792	270,683	4,959	2000	30.2	70.4	6.7	1.1
2001	848,694	4,977,240	51,826	3,629	2001	22.7	63.0	3.7	0.3
2002	475,106	6,101,261	190,140	5,913	2002	27.7	70.5	5.3	1.2
2003	472,357	5,468,252	506,730	8,120	2003	29.0	74.3	5.6	1.4
2004	344,948	3,990,996	34,480	8,065	2004	27.3	68.9	4.2	0.7
2005	479,497	8,842,863	55,783	3,534	2005	24.2	71.4	5.0	0.4
2006	848,632	14,329,920	95,359	5,043	2006	25.1	66.0	6.0	1.8
2007	363,459	16,209,462	254,311	4,956	2007	33.3	92.3	6.9	0.5

Yields

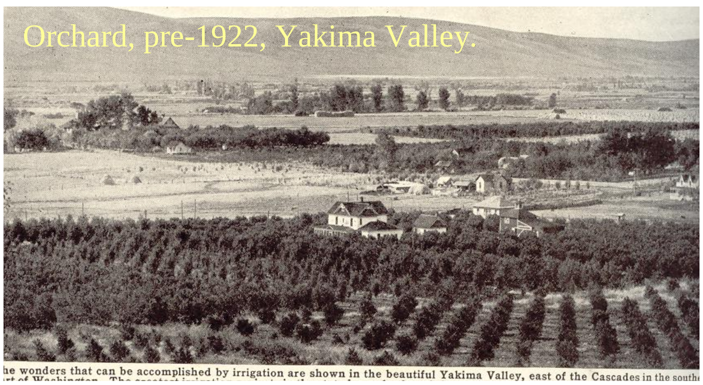
	Granger	Sulphur	Spring	Snipes
Median total suspended solids (lb/ac/day)				
1997	0.47	0.39	0.011	0.005
1998	0.34	0.13	0.005	0.001
1999	0.26	0.25	0.009	0.003
2000	0.28	0.23	0.021	0.003
2001	0.14	0.18	0.004	0.003
2002	0.37	0.57	0.005	0.001
2003	0.21	0.44	0.003	0.001
2004	0.24	0.45	0.003	0.001
2005	0.27	0.88	0.006	0.0009
2006	0.38	0.42	0.008	0.001
2007	0.26	0.57	0.004	0.001
Median nitrate+nitrite (lb/ac/day)				
1997	0.04	0.06	0.012	0.006
1998	0.03	0.05	0.009	0.005
1999	0.03	0.05	0.012	0.003
2000	0.03	0.05	0.018	0.003
2001	0.02	0.04	0.009	0.001
2002	0.03	0.05	0.013	0.003
2003	0.03	0.05	0.011	0.003
2004	0.03	0.05	0.011	0.001
2005	0.03	0.05	0.013	0.002
2006	0.03	0.05	0.015	0.005
2007	0.03	0.06	0.016	0.001
Median fecal coliform (col/sec/ac)				
1997	416	346	82	0.3
1998	77	148	51	1.9
1999	51	429	42	0.9
2000	72	174	25	0.9
2001	35	140	5	0.6
2002	19	172	17	1.1
2003	20	154	46	1.4
2004	14	112	3	1.4
2005	20	249	5	0.5
2006	40	403	7	9.5
2007	15	456	16	0.9
Median seasonal discharge (ac-ft/ac/165 days)				
1997	0.33	0.47	0.16	0.06
1998	0.29	0.45	0.09	0.08
1999	0.31	0.47	0.11	0.06
2000	0.31	0.42	0.16	0.06
2001	0.25	0.33	0.09	0.02
2002	0.29	0.37	0.14	0.07
2003	0.29	0.41	0.14	0.09
2004	0.28	0.37	0.10	0.08
2005	0.26	0.38	0.13	0.04
2006	0.26	0.34	0.16	0.11
2007	0.30	0.46	0.20	0.06

	Granger	Sulphur	Spring	Snipes
Median total phosphorus (lb/ac/day)				
1997	0.0023	0.0028	0.0002	0.0002
1998	0.0009	0.0018	0.0002	0.0001
1999	0.0009	0.0028	0.0001	0.0001
2000	0.0011	0.0018	0.0002	0.0001
2001	0.0007	0.0015	0.0001	0.0000
2002	0.0010	0.0023	0.0001	0.0001
2003	0.0009	0.0021	0.0002	0.0001
2004	0.0010	0.0019	0.0001	0.0001
2005	0.0008	0.0024	0.0002	0.0001
2006	0.0011	0.0053	0.0002	0.0001
2007	0.0009	0.0053	0.0002	0.0000
Median total Kjeldahl nitrogen (lb/ac/day)				
1997	0.006	0.010	0.001	0.001
1998	0.002	0.006	0.000	0.000
1999	0.002	0.011	0.000	0.000
2000	0.002	0.006	0.001	0.000
2001	0.001	0.006	0.000	0.000
2002	0.002	0.007	0.001	0.000
2003	0.002	0.009	0.001	0.000
2004	0.002	0.007	0.001	0.000
2005	0.002	0.008	0.001	0.000
2006	0.002	0.010	0.001	0.001
2007	0.003	0.007	0.001	0.000
Median total dissolved solids (lb/ac/day)				
1997	2.6	3.5	1.2	0.5
1998	2.2	3.4	0.7	0.6
1999	2.3	3.6	0.8	0.4
2000	2.3	3.1	1.2	0.4
2001	1.7	2.5	0.7	0.1
2002	2.1	2.8	1.0	0.4
2003	2.2	3.0	1.0	0.5
2004	2.1	2.8	0.8	0.3
2005	1.9	2.9	0.9	0.1
2006	1.9	2.7	1.1	0.6
2007	2.1	3.7	1.1	0.2

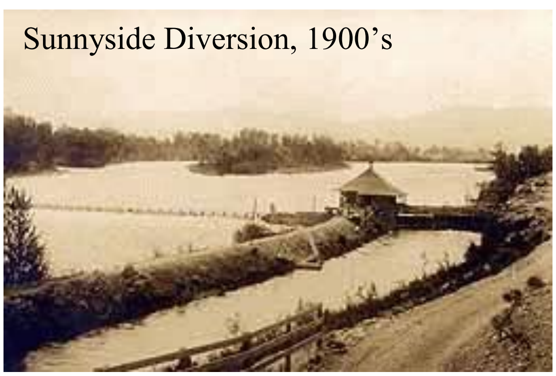
Photo Gallery.



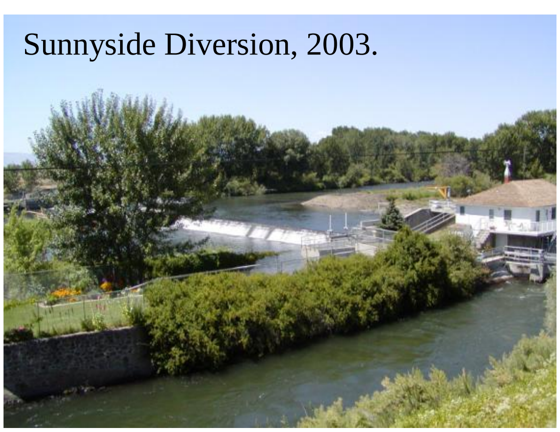
Furrow irrigation, pre-1922, Yakima Valley.



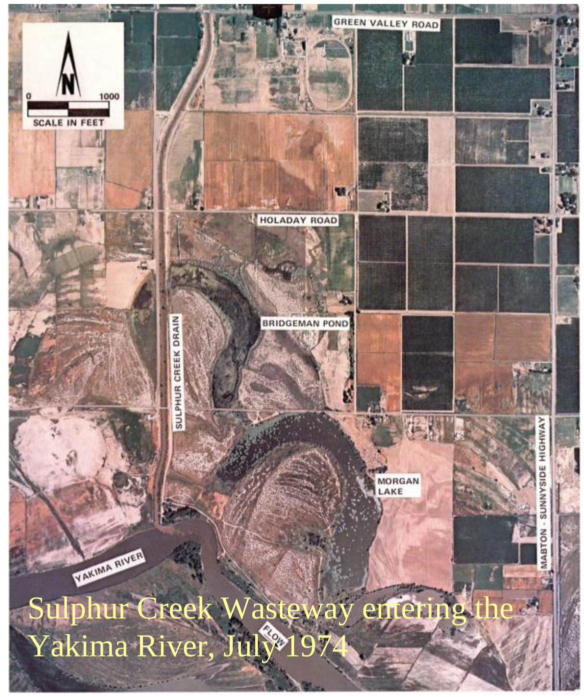
Orchard, pre-1922, Yakima Valley.



Sunnyside Diversion, 1900's

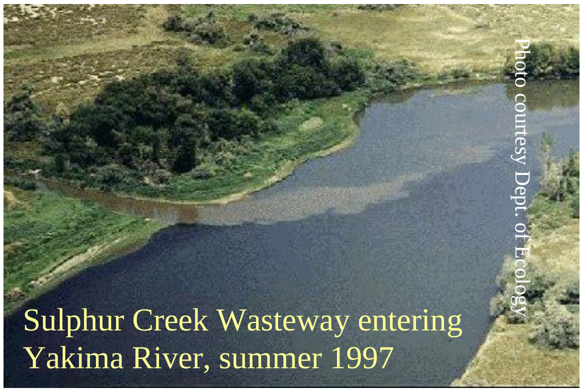


Sunnyside Diversion, 2003.

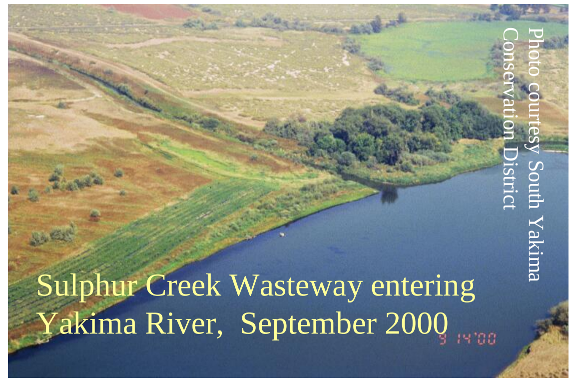


Sulphur Creek Wasteway entering the Yakima River, July 1974

Sulphur Creek Wasteway entering the Yakima River, September 2007



Sulphur Creek Wasteway entering Yakima River, summer 1997



Sulphur Creek Wasteway entering Yakima River, September 2000

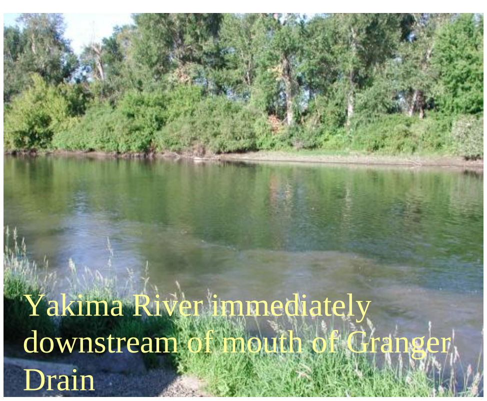

Solid set sprinkler irrigation, July 2002

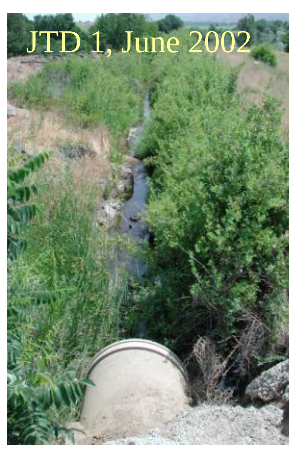

Rill (furrow irrigation), June 2002

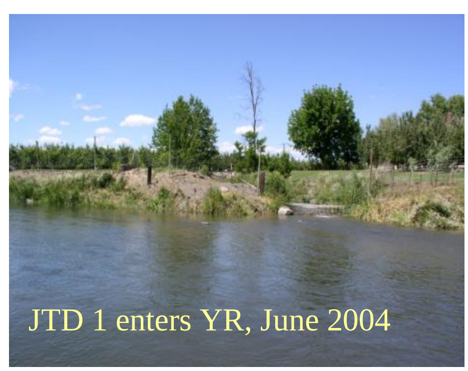

Drip irrigation, August 2001


Center pivot, April 2002


JD 51.4 enters YR, June 2004


Yakima River immediately downstream of mouth of Granger Drain


JTD 1, June 2002


JTD 1 enters YR, June 2004