

# RIVER-AQUIFER EXCHANGES IN THE TWISP RIVER, WASHINGTON

Christopher P. Konrad<sup>1</sup>

**ABSTRACT:** The U.S. Geological Survey has been investigating river-aquifer exchanges along the lower 15 km of the Twisp River of north-central Washington to elucidate the seasonal patterns in ground-water discharge to the river and the effects of irrigation-canal seepage on aquifer recharge and base flow. The Twisp River consistently gained flow from Nov. 1, 2000 to Apr. 23, 2001 with a mean net ground-water discharge to the river of 0.13 m<sup>3</sup>/s (4.6 cfs) or 11 percent of mean discharge of the Twisp River near Twisp for the period. River-aquifer exchanges fluctuated during the high-flow period from Apr. 23 to July 25, 2001, with alternating periods of gains and losses in streamflow. The river returned to a gaining condition on July 26, with a mean net ground-water discharge to the river of 0.41 m<sup>3</sup>/s (14 cfs) from Aug. 15 to Oct. 15 or 60 percent of mean discharge of the Twisp River near Twisp for the period. The combined seepage rate from two irrigation canals in the lower Twisp River valley was estimated to be 0.2 m<sup>3</sup>/s (7 cfs) in June and July 2001 but likely decreased during the late summer. Seepage from the irrigation canals recharged shallow aquifers and, in turn, may have marginally increased the rate of ground-water discharge to the river during the late summer and early autumn. Snowmelt and bank storage during high flows also recharged aquifers helping to support ground-water discharge to the river during low-flow periods.

**KEY TERMS:** river-aquifer exchanges, low flow, irrigation.

## INTRODUCTION

Winter rainfall and spring snowmelt produce much of the runoff from river basins in the western United States, but ground-water discharge sustains streamflow during dry periods that often extend from late summer into the winter. Streamflow in the Twisp River of north-central Washington during low-flow periods is critical for the incubation and rearing of three Federally threatened and endangered aquatic species (spring-run chinook salmon, steelhead, and bull trout) (Code of Federal Regulations, 2001a and 2001b) but also provides a source of water for agricultural and residential uses. In response to this issue, Washington State established minimum instream flows in the Twisp River (Washington Administrative Code, 2001), which limit new appropriations of surface water.

In November 2000, the U.S. Geological Survey (USGS) initiated an investigation of river-aquifer exchanges in the lower 15 km of the Twisp River from Newby Creek to a point about 3 km upstream of the confluence of the Twisp and Methow Rivers to elucidate the seasonal patterns in ground-water discharge to rivers and the effects of irrigation practices on aquifer recharge. The objectives of the investigation were to (1) document the exchanges between the river and the aquifers in the lower valley particularly during low-flow periods; (2) estimate the rate of aquifer recharge from irrigation ditches, and (3) assess the effect of irrigation-induced recharge on low flow in the Twisp River.

The Twisp River drains a 630-km<sup>2</sup> basin on the eastern side of the Cascade Range in north-central Washington. Mean annual precipitation in the Twisp River Basin varies with altitude and ranges from 200 mm at low altitudes to 2,000 mm at high altitudes in the Cascade Range. Snow is the predominant form of precipitation in the basin. Mean annual runoff for the Twisp River near Twisp is 7.4 m<sup>3</sup>/s (262 cfs), which is equivalent to an average of 370 mm/yr from the basin area, based on USGS records for water year (WY) 1975-79 and 1991-2001. The annual peak discharge of the Twisp River occurs in May and June during periods of snowmelt. Flow in the Twisp River decreases in the late summer to a minimum in September when mean monthly discharge was 1.4

---

<sup>1</sup> Hydrologist, U.S. Geological Survey, 1201 Pacific Ave., Suite 600, Tacoma, WA, 98402, Phone: (253) 428-3600, Fax: (253) 428-3614, E-Mail: cpkonrad@usgs.gov

m<sup>3</sup>/s (49 cfs) for WYs 1975-79 and 1991-2001. During low-flow periods, streamflow is primarily generated by ground-water discharge with relatively minor contributions from snowfields, glaciers, and lakes.

The study area includes the lower 15 km of the Twisp River from Newby Creek to a point approximately 3 km upstream of the confluence of the Twisp and Methow Rivers. The lower Twisp River valley has two major irrigation systems with surface-water diversions, the Twisp Valley Power and Irrigation Company (TVPI) and the Methow Valley Irrigation District (MVID). The diversion for the TVPI canal is 0.5 km downstream (east) of Newby Creek on the north side of the Twisp River. The TVPI canal runs parallel to the river for 6.6 km and ends 3 km west of Twisp at a culvert that returns unused water to the river. The diversion for the MVID west canal is 5 km downstream of Newby Creek on the south side of the Twisp River. The MVID west canal runs parallel to the river for 5 km before leaving the Twisp River valley. The U.S. Geological Survey (USGS) operates gaging stations on both of the irrigation canals.

## METHODS

A mass-balance approach was used to calculate the daily net exchange of flow between the aquifers and the river from Nov. 1, 2000 to Oct. 30, 2001. The daily net exchange was calculated as the difference between daily mean inflows and outflows with a positive net exchange, which indicates ground-water discharge to the river. Inflow to the study reach was measured continuously at the USGS stream-gaging station on the Twisp River above Newby Creek (station number 12448990). Tributary inflows from Newby and Poorman Creeks were measured in May and June 2001 but were less than 1 percent of the discharge of the Twisp River above Newby Creek. As a result, tributary inflow was not accounted for in the mass balance. Return flows from the TVPI canal were estimated daily from a staff plate near the end of the canal, however, a portion of the return flow was used on occasion downstream of the staff plate. The estimated daily TVPI return flow on these occasions may be higher than the actual return flow to the Twisp River on some days. MVID west canal has no return flows to the Twisp River. The primary outflows from the study area were measured continuously at the USGS gaging stations on the Twisp River near Twisp (12448998) and at the diversions to the TVPI canal (12448992) and MVID west canal (12448996). The calculated daily mean discharge at the gages was assessed to be within 8 percent of actual discharge 95 percent of the time.

In addition to collecting continuous records of streamflow, USGS made miscellaneous measurements at selected sites on the Twisp River and irrigation canals. Twisp River discharge was measured at four points between the two gages in September 2001 to document spatial patterns of gains and losses during low-flow conditions. Discharge was measured at a series of points along each of the irrigation canals to calculate seepage rates. Seepage runs were done in June, July, August, and October on the TVPI canal and in July and August on the MVID west canal. The seepage runs on the TVPI canal during the summer covered 43 percent of the total length of the canal and excluded any appreciable water users. The seepage run on the TVPI canal in October covered the entire length of the canal (all uses had ceased). The seepage runs on the MVID west canal covered the total length of the canal in the Twisp River Basin but, as a result, included water users. As a result, actual seepage from the MVID west canal was less than the calculated rate. The infiltration rate, with units of [L/T], for the selected sections of canals was calculated for each segment as the seepage rate divided by the canal's basal area (wetted width x canal length) between measurement points.

Ground-water levels in six monitoring wells were recorded beginning in May 2001 to evaluate the ground-water response to irrigation canal seepage and to assess the relation between river-aquifer exchanges and ground-water levels. The wells were arrayed in three pairs on the north side of the river. River stage was monitored in conjunction with each pair of wells to estimate the cross-valley hydraulic gradients between ground and surface waters at three sites. The upstream site was 1.2 km downstream of the TVPI diversion. The wells straddled the TVPI canal, 200 and 400 m north of the river in the bottom of a dry, side valley (Elbow Coulee). The aquifer at the upstream site is confined in unconsolidated (sands, gravel, and clay) glacial deposits underlain by fractured shale.

The middle site was located 4 km downstream of the TVPI diversion. Both wells were between the river and the TVPI canal. The wells were 80 and 120 m north of the river on a hillslope forming the southern edge of a large

(3 km long, 1 km wide) unconsolidated glacial terrace. The aquifer is confined in unconsolidated glacial deposits underlain by shale.

The downstream site was located 6 km downstream of the TVPI diversion. Both wells were between the river and the TVPI canal. One well was located on top of the large terrace, 160 m north and 24 m above the river. The well penetrates through the terrace into a confined aquifer in an igneous formation below the elevation of the river. The other well is located on the floodplain below the terrace, 80 m north of the river. The aquifer is confined in unconsolidated alluvial deposits. Ground-water levels were measured hourly from May through October 2001 with a non-submersible pressure transducer and recorded with a data logger. Water levels were measured manually about once every 2 months.

#### SURFACE-WATER CONDITIONS IN WY 2001

Annual mean discharge in WY 2001 of the Twisp River was 3.1 m<sup>3</sup>/s (108 cfs) above Newby Creek and 2.8 m<sup>3</sup>/s (100 cfs) near Twisp. Maximum daily discharge, on May 24, 2001, was 31.4 m<sup>3</sup>/s (1110 cfs) above Newby Creek and 33.4 m<sup>3</sup>/s (1180 cfs) near Twisp. The lowest daily mean discharge for the Twisp River above Newby Creek was 0.68 m<sup>3</sup>/s (24 cfs) on 3 days in September. The lowest daily mean discharge for the Twisp River near Twisp was estimated to be 0.42 m<sup>3</sup>/s (15 cfs) on 4 days in September and equaled the lowest recorded daily mean discharge based on a 16-year streamflow record.

The TVPI and MVID West canals diverted water from the Twisp River at a mean combined rate of 0.82 m<sup>3</sup>/s (29 cfs) from Apr. 29, to Oct. 15, 2001. Diversions were highest during the early summer with a monthly mean rate of 0.94 m<sup>3</sup>/s (33 cfs) in July, which was equal to 21 percent of monthly mean discharge of the Twisp River above Newby Creek. Combined diversions decreased to a monthly mean rate of 0.60 m<sup>3</sup>/s (21 cfs) in September, which was equal to 79 percent of the monthly mean discharge of the Twisp River above Newby Creek. Diversions to the MVID west canal were stopped on four occasions (for 1 to 3 days each) from Aug. 21, to Sept. 25, 2001.

Inflows from tributaries and return flow from the TVPI canal were relatively minor components of the water budget. The combined tributary discharge of Newby and Poorman Creeks was 0.05 m<sup>3</sup>/s (1.6 cfs) on May 9-10, 2001 (0.7 percent of daily inflow to the reach) and was 0.02 m<sup>3</sup>/s (0.6 cfs) on June 5-6, 2001 (0.2 percent of daily inflow). Flow in both of these creeks continued to decrease through the summer. Maximum estimated return flow from TVPI averaged 0.04 m<sup>3</sup>/s (1.3 cfs) from May 1 to Oct. 15, 2001.

#### RIVER-AQUIFER EXCHANGES

The net ground-water inflow to the river over the 15 km study reach was 0.12 m<sup>3</sup>/s (4.2 cfs) from Nov. 1, 2000 to Oct. 30, 2001. Exchanges between the aquifer and Twisp River in the lower valley can be divided into three distinct temporal regimes (Figure 1). Under the dominant regime, which prevailed during low flows from Nov. 1, 2000 through Apr. 23, 2001, the river had a consistent gain of 0.13 m<sup>3</sup>/s (4.6 cfs), with a standard deviation of daily mean exchange of 0.04 m<sup>3</sup>/s, that accounted for as much as 21 percent of the daily mean discharge in the Twisp River near Twisp.

The second regime, which occurred during high flows from Apr. 24 to July 25 2001, was characterized by alternating losses and gains. The second regime started when the river rose on April 25 and began to lose flow. The largest magnitude exchanges of the year had daily mean values ranging from -1.0 to 3.0 m<sup>3</sup>/s (-35 to 110 cfs) and occurred during the second regime. The highest loss rates, 1 m<sup>3</sup>/s (35 cfs), occurred on May 12 and was followed by a brief (2 day) gaining period that coincided with the first snowmelt peak (May 14). After another week of losing flow, the river gained flow during the period of maximum runoff in the basin (May 23 to June 14) at rates as high as 3 m<sup>3</sup>/s (110 cfs). This gaining period was followed by the longest losing period for the river from June 15 to July 25, after which the river returned to a gaining condition for the rest of the year. Losses during high flows were likely a result of bank storage while gains were likely a combination of increased ground-water inflow to the study area and release of bank storage.

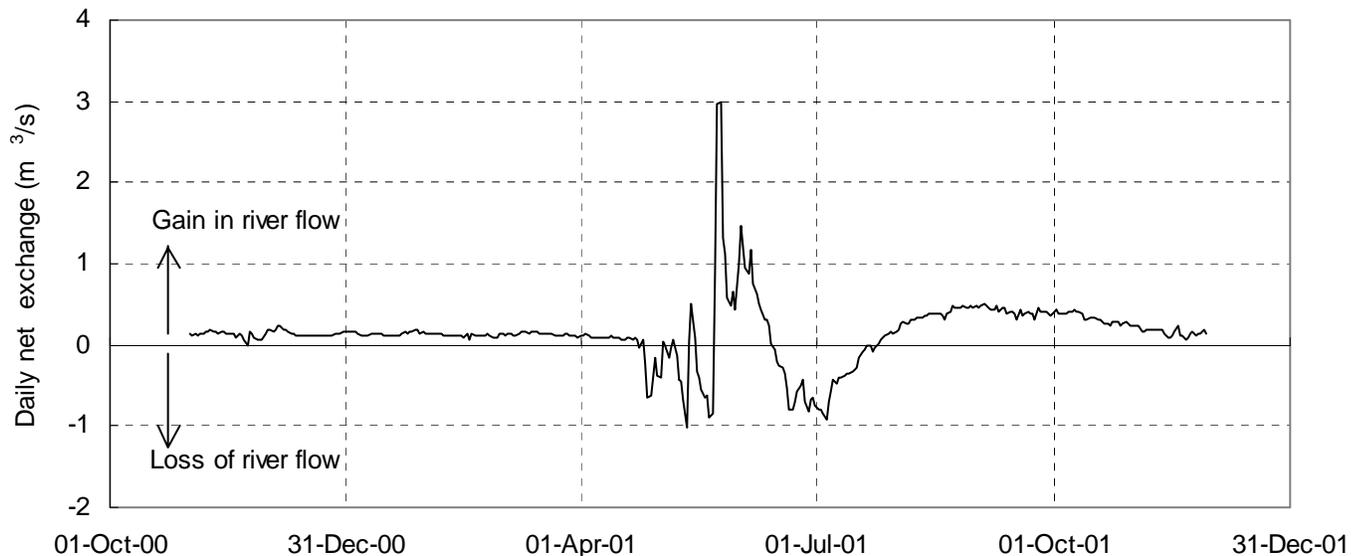


Figure 1. Daily net exchange between the Twisp River and aquifers in the lower Twisp River valley.

The third regime from July 26 to October 15 represented the river's return to a consistently gaining condition, however, the rate of ground-water inflow to the river was higher than under the first regime. The mean net ground-water inflow to the Twisp River was 0.41 m<sup>3</sup>/s (14 cfs) (standard deviation = 0.05 m<sup>3</sup>/s) for Aug. 15 through Oct. 15, 2001. Ground-water inflow to the lower reach accounted for 28 to 96 percent of the daily mean discharge for the Twisp River near Twisp under the third regime. The largest relative gain in streamflow for any month occurred during September 2001 when the net ground-water inflow on average accounted for 69 percent of the daily mean discharge and 60 percent of the monthly mean discharge of the Twisp River near Twisp.

The magnitude of the gain began to decrease from a monthly mean of 0.33 m<sup>3</sup>/s (12 cfs) in October 2001 to a monthly mean of 0.16 m<sup>3</sup>/s (5.6 cfs) in November 2001. The magnitude of the gain decreased in November 2001, which may represent a transition back to the first regime of aquifer-river exchange.

Discharge measurements made at points along the Twisp River on September 11, 2001 resolved some of the spatial patterns in river-aquifer exchanges (Table 1). Mean daily discharge at the gaging station near Twisp was 0.93 m<sup>3</sup>/s (33 cfs) with a 95-percent confidence interval of +/- 0.07 m<sup>3</sup>/s (2.5 cfs). The net ground-water discharge to the river was 0.4 m<sup>3</sup>/s (14 cfs) based on the difference between inflow above Newby Creek and the combined outflow of river discharge at the gaging station near Twisp and the TVPI diversion. The MVID west canal did not divert water from the Twisp River during the seepage run. Nearly all of the gain in streamflow occurred in three reaches comprising only 61 percent of the length of the river between Newby Creek and the gaging station near Twisp. The mean rate of increase in streamflow was 0.05 (m<sup>3</sup>/s)/km (2.8 cfs/mi) in the three strongly gaining reaches.

Table 1. Net exchanges between aquifer and lower Twisp River for Sept. 11, 2001.

Reach	Net exchange [m <sup>3</sup> /s]	Net exchange per unit channel length [m <sup>3</sup> /s/km]
Newby Creek to TVPI	0.01*	0.01*
TVPI to Poorman Creek	0.16	0.04
Poorman Creek to MVID west diversion	-0.03*	-0.01*
MVID West to Elbow Canyon	0.10	0.05
Elbow Canyon to gaging station near Twisp	0.16	0.05

\*Net exchange is not significant as it falls within the 95-percent confidence interval for discharge measurements.

## GROUND-WATER LEVELS

Ground-water levels in the six monitoring wells displayed a wide variety of seasonal changes. At the upstream site in Elbow Coulee, ground-water levels averaged 6.4 m (21 ft) higher in the north well (upgradient of the TVPI canal) than in the south well (between the TVPI canal and the Twisp River). Ground-water levels at the upstream site reached a maximum in late May and declined through the summer and autumn. The water level in the north well declined 0.4 m (1.3 ft) from June to November 2001. The water level in the south well declined 1.3 m (4.3 ft) from June to November. The rate of water-level decline was consistent in each well, except from October 15-30, when the water levels in the south well declined more rapidly. The water level in the south well averaged 4.8 m (16 ft) above river stage, indicating a strong hydraulic gradient (about 2 percent) driving ground water to the river. The Twisp River flow gained 0.16 m<sup>3</sup>/s (5.6 cfs) in reach between TVPI and Poorman Creek in September 2001 (Table 1), which was likely produced, in part, by ground-water discharge from the aquifer in Elbow Coulee.

Ground-water levels at the middle site were much more variable than at the upstream site and did not begin to decline systematically until mid-July. Throughout the monitoring period, the water levels in the two wells rose and declined in synchrony with no more than 0.07 m (0.2 ft) difference at any time. The water levels of both wells declined 0.5 m (1.6 ft) from July to November. Water levels in the wells were higher than river stage, with differences ranging from 0.08 m (0.3 ft) on May 14 to 0.88 m (2.9 ft) on July 18, but the hydraulic gradient (0.001 to 0.01) was lower than at the upstream site. During September 2001, the river's transition from a strongly gaining reach (TVPI to Poorman Creek) to a relatively neutral condition (Poorman Creek to MVID west canal) downstream of the middle site generally was consistent with the lower hydraulic gradient observed at this site compared to the upstream site.

Ground-water levels in wells at the downstream site showed divergent seasonal patterns. The water level in the north well completed in bedrock beneath the large glacial terrace on the north side of the lower valley, rose 1.7 m (5.6 ft) from May to September 2001. The water level in the north well initially was lower than river stage, but rose above river stage in early July and remained so until late November when water levels in the well and river were equal. The water level in the south well averaged 1.1 m (3.6 ft) lower than river stage and varied consistently with river stage. Although the river was likely recharging the shallow aquifer at the south well, the river was gaining flow in this reach (Elbow Canyon to the gaging station near Twisp in Table 1). The gain is consistent with the hydraulic gradient between the north well and the river.

## EFFECTS OF IRRIGATION-CANAL SEEPAGE ON RIVER-AQUIFER EXCHANGES

Calculated infiltration rates for the irrigation canals varied greatly from segment-to-segment and over time. The infiltration rate averaged 0.04 m/d (0.1 ft/d) for selected segments of the TVPI canal. Infiltration rates for the selected segments were likely higher than in other parts of the TVPI canal because of geologic conditions. In August 2001, seepage from the selected segments of the TVPI canal decreased by 75 percent and was equivalent to an infiltration rate of 0.01 m/d (0.03 ft/d). At the end of the irrigation season, measured total seepage from the TVPI canal was 0.01 m<sup>3</sup>/s (0.4 cfs), which was equivalent to an infiltration rate of 0.006 m/d (0.02 ft/d) averaged over the basal area of the canal. The calculated infiltration rate for the MVID west canal was 0.02 m/d (0.07 ft) in July and August 2001, however, the actual rate was lower because the calculated rate included water use in addition to canal seepage.

The combined seepage from the TVPI and MVID west canals were estimated using the range of calculated infiltration rates. Assuming an average infiltration rate of 0.02 m/d (0.06 ft/d) for both canals, their combined seepage rate would have been 0.2 m<sup>3</sup>/s (7 cfs) in the study area and represents the likely maximum rate of aquifer recharge from the canals during the irrigation season. If the average infiltration rate decreased to 0.006 m/d (0.02 ft/d), the seepage from the canals would have recharged ground water at a rate of 0.05 m<sup>3</sup>/s (1.8 cfs) in the study area.

Although ground-water levels indicated aquifer recharge in the study area from snowmelt and bank storage during high flows, they also provide evidence that canal seepage was a source of recharge during the third

regime of river-aquifer exchanges. The water level in the north well at the upstream site (upgradient of the TVPI canal) rose during May, indicating aquifer recharge, but began to decline in June. The south well at the upstream site showed a similar pattern, as would be expected if regional ground-water flow rather than irrigation-canal seepage was the dominant process controlling water levels. However, the water level in the south well briefly declined at a higher rate when diversions to the TVPI canal ceased in October. The more rapid decline in water level was not exhibited in the north well. In this case, irrigation-canal seepage may have elevated ground-water levels by as much as 0.3 m (1 ft) near the south well. Ground-water levels in both wells at the middle site remained high after the peak snowmelt and runoff in May and began to decline in July at the same time as the decrease in the TVPI diversion. At the downstream site, the water level in the north well rose through the summer and maintained a high level until mid-October when it began to decline. This pattern was unlikely to be a result of natural recharge, unless the aquifer had distant recharge areas and low transmissivity such that ground-water levels responded 2 to 4 months after snowmelt.

The increased ground-water discharge to the Twisp River from August through October 2001 is consistent with the response of water levels in the south well of the upstream site and the north well of the downstream site to irrigation-canal seepage. Although some of the increased ground-water discharge may be a result of bank storage during high flows, the volume of water lost from the lower river during high flows is gained back by August 14. Thus, the source of increased ground-water discharge during the late summer is likely seepage from the irrigation canals.

## CONCLUSIONS

Exchanges between aquifers and the lower Twisp River exhibited distinct seasonal patterns associated with streamflow patterns, ground-water levels, and seepage from irrigation canals. The river gained flow during low-flow periods and fluctuated between gaining and losing flow during high-flow periods. Ground-water discharge to the Twisp River occurred primarily in three of five reaches and was consistent with the direction of hydraulic gradients between river stage and ground-water levels in both wells at the upstream site and in the north well at the downstream site. Net ground-water inflow to the river was consistently higher from Aug. 15 to Oct. 15, 2001 (mean rate of 0.41 m<sup>3</sup>/s or 14 cfs) than from Nov. 1, 2000 to April 23, 2001 (mean rate of 0.13 m<sup>3</sup>/s or 4.6 cfs). River-aquifer exchanges were important during the low-flow period from Aug. 15 to Oct 15, 2001 when ground-water inflow averaged 69 percent of the daily mean discharge of the Twisp River near Twisp. By November 2001, ground-water inflow had decreased to a monthly mean rate of 0.16 m<sup>3</sup>/s (5.6 cfs). The combined seepage rate from the irrigation canals was estimated to be at most 0.2 m<sup>3</sup>/s (7 cfs) in June and July but was likely to have decreased during the late summer. Seepage from the irrigation canals in the lower Twisp River valley recharged shallow aquifers and, in turn, may have marginally increased the rate of ground-water discharge to the river during the late summer and early autumn. Snowmelt and bank storage during high flows also recharged aquifers helping to support ground-water discharge to the river during low-flow periods.

## REFERENCES

- Code of Federal Regulations, 2001a, Title 50, Volume 1, Wildlife and Fisheries. Chapter I--U.S. Fish and Wildlife Service, Part 17 - Endangered and threatened wildlife and plants. Sec. 17.11 - Endangered and threatened wildlife. U.S. Government Printing Office, 50 CFR 17.11.
- Code of Federal Regulations, 2001b, Title 50, Volume 2, Wildlife and Fisheries. Department of Commerce, Part 224 - Endangered marine and anadromous species. Sec. 224.101 -- Enumeration of endangered marine and anadromous species. U.S. Government Printing Office, 50 CFR 224.101.
- Washington Administrative Code, 2001, Water Resources Program in the Methow River Basin, WRIA 48, Section 020, Establishment of base flows. Washington State Legislature Chapter 173-548 WAC.