

Golf Course Water Reuse Pilot Study

Phase III Final Report and Project Summary

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Phase III - 2009 Soil, Water, and Turfgrass Tissue Sampling and Analysis and Turfgrass Quality Evaluation at Two City of Spokane Golf Courses and Overall Project (2008-2009) Summary and Conclusions

Objective:

To determine the long-term (two year) effects of irrigation with reuse water compared to non-effluent city/pond water, on soil chemical and physical properties and turfgrass tissue and quality parameters at two City of Spokane golf courses under conditions of routine management and play.

Phase III Tasks and Materials & Methods:

Details of Phase III tasks and protocol were previously outlined (May 2009 City of Spokane Golf Course Water Reuse Pilot Study – Phase III Scope of Work). During Phase III, as was done in Phase I and Phase II (2008), soil, plant, water quality, and turfgrass parameters were evaluated throughout the 2009 turfgrass growing season. Sampling was performed at two City of Spokane golf courses: Downriver and The Creek at Qualchan Golf Course. This Pilot Study is a demonstration that will identify numerical, but not statistical, differences and trends among treatments. This is due to the lack of replication of experimental units in the experimental design, which was developed prior to WSU's involvement in the project, and new construction and reconstruction of two sites; therefore, statistical comparison cannot be made among treatments.

Task 1. Soil sampling and analysis (Basic soil test and CEC).

Soil samples were obtained from each golf course three times (15 May, 17 Aug., and 15 Oct. 2009) during the 2009 turfgrass growing season. A basic soil test and soil cation exchange capacity (CEC), a measure of the amount of exchangeable cations in the soil, were performed on each sample by Harris Laboratories. As in 2008, due to the extremely rocky soil at the

Downriver #7 rough site, soil was sampled to a depth of approximately 2 in. and not to the typical turfgrass soil sampling depth of 4 in., which was the sampling depth at all the other golf course sites.

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Results.

Soil test (Downriver).

Downriver #7 rough basic soil test (Table 1) indicated some differences between sites receiving reuse water or city water for irrigation. The pH was similar regardless of irrigation water source and was in the optimum range. Soil pH plays a large role in the availability of essential plant nutrients; therefore, pH levels too high or too low results in some nutrients not being available for normal plant growth. Percentage of organic matter (OM) tended to be about twice as high where city water was used compared to the reuse water site on the May and August 2009 sampling dates, but were similar at the final sampling date (15 Oct.). This is most probably due to the way the samples were taken. It appears that at least for the city water sampling, the top thatch layer may not have been removed by the personnel taking those samples; therefore, this would lead to higher OM content. Furthermore, it was very difficult to sample these areas due to the in the rocky nature of the soil. The effective sampling depth was 2 in., not the standard 4 in. that is recommended. However, on the final sampling date, regardless of irrigation water source, OM levels were similar. Soil NO₃-N (nitrate) levels were nearly twice as high where reuse water was applied compared to the city water site in May and August; however, soil nitrate levels were much higher at the October sampling date in the soil where city water was applied than where reuse water was applied.

Phosphorus (P), potassium (K), and SO₄-S (sulfate) levels tended to be higher where reuse water was applied compared to the city water site, but at the final sample date they were similar at each site. Boron (B) at 0.8 ppm in the reuse irrigation water area was above the optimum range (0.3-0.5 ppm). Boron was also high, 0.7 ppm, on the last sample date for city water. Boron is of concern because small amounts of B can be phytotoxic to plants; however, more so to ornamentals than turfgrasses. Sodium (Na) levels tended to be much higher in the soil irrigated with reuse water compared to city water in May and August, but surprisingly Na levels were similar at the October sampling date. One would expect that the trend of lower Na levels in the area irrigated with city water would continue throughout the growing season, since there are very low levels of Na in the city water compared to the reuse water (Table 7).

At Downriver #7 rough, the basic soil test electrical conductivity (EC) was in the optimum range and similar regardless of irrigation water source (Table 1). Electrical conductivity or soluble salts (SS), is a measure of the salt content (salinity) of the soil. Even though the soluble salt levels in the reuse water are twice as high compared to city water (Table 7) there appears to be no real effect on soil EC to date. Elevated salt levels (especially Na) can cause poor soil structure, water drainage, and plant growth. Soil salinity should be monitored regularly, since salt levels are often high in reuse water (Harivandi, 2004). This coupled with poor soil drainage can result in hastening poor plant growth conditions.

Downriver #7 rough soil test CEC was higher where the city water was used in May and August compared to reuse water, which closely corresponds with higher OM levels at this site. One would expect higher CEC levels in these cases.

Downriver #6 tee soil pH levels were a little higher compared to #7 rough, but not excessively high regardless of water source used for irrigation (Table 1). Controlling soil pH should be a concern since both city and reuse water have a high pH (Table 7). There are various ways to lower soil pH, for example, the use of ammonium based fertilizers or elemental sulfur. The OM and nitrate levels were similar between the two water sources. Phosphorus level on 17 Aug. 2009 was much lower compared to city water, but in general, P, K, and sulfate levels were higher where reuse water, compared to city water, was applied on the tee. The EC levels were all within optimum range regardless of water source. However, Na levels were much higher on the tee that received reuse water compared to city water. Sodium levels also increased over time.

The CEC for the #6 tee are much lower than those measured for the #7 rough due to the high sand content and lower percentage of OM in the tee (Table 1). The CEC levels were slightly higher on the area of the tee receiving reuse water. These data suggests that the CEC would be lower where reuse water was applied, since there are higher levels of Ca, Mg, and Na competing for exchange sites while OM remains the same.

Soil test (Qualchan).

At Qualchan, #15 green was reconstructed in late 2008 with a new sand profile and sod from the old green was reused and put back in the same area on the new green. In addition, a newly constructed #16 back tee (back tee site received reuse irrigation water) makes comparisons at these two sites over time difficult. In any event, #15 green showed similar soil pH and OM content regardless of irrigation source (Table 2). Soil pH levels were a little high, but expected based on the type of sand used to construct the green. However, the area of the green that received reuse water, for the most part, had slightly higher levels of nitrate, P, K, and sulfate. Sodium levels were higher and increased as the growing season progressed where reuse water was applied compared to the area of the green that received pond water. CEC was the same regardless of irrigation water source.

Making comparisons between the new #16 back tee, which was planted in mid-June 2008, and the older, established #16 forward tee is very difficult (Table 2). As was observed in 2008, overall the new #16 tee irrigated with reuse water showed higher pH levels and lower nutrient levels than the older #16 tee irrigated with pond water. This was most likely due to the high sand content, also the sand has a high pH, and very low percentage of OM in the newly constructed #16 tee, which resulted in low nutrient holding capacity. This is also reflected in the low soil CEC of the #16 reuse water site. Not surprisingly, as mentioned in the Phase II report, the nutrient holding capacity of the new #16 tee should increase over time, but still was not as high as the older #16 tee (pond water irrigation) by the conclusion of the study. Sodium levels were higher and increased during the summer on the reuse tee compared to the older tee irrigated with pond water.

Soil pH levels on the #16 fairway reuse or pond water irrigation sites were the same and within the optimum range (Table 2). However, OM content was slightly higher where the pond water was applied as opposed to where reuse water was applied. Nitrate levels were higher in the reuse area of the fairway, with lower levels of P and K, and no difference in sulfate levels. Boron levels were essentially the same and, for the most part, within the safe range. Sodium

levels were higher and increased where reuse water was applied compared to pond water. CEC was similar regardless of irrigation source.

At Qualchan, EC at all locations and irrigation treatments were at satisfactory levels throughout the growing season.

Task 2. Soil sampling and analysis (Trace Element Screen [heavy metals], Mercury, and Soil Physical Properties).

Soil samples were taken in 2008 (Phase I), at the beginning of the study, to determine the baseline soil heavy metal levels (trace element screen and mercury) and again on 15 Oct. 2009, at the end of the study, to determine if soil heavy metal levels changed. Soil samples were analyzed by the Analytical Sciences Laboratory (ASL) at the University of Idaho.

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Results.

Final soil heavy metals:

The final soil heavy metal levels taken at the end of the study (15 Oct. 2009) are presented in Tables 3 and 4 for Downriver and Qualchan, respectively. In 2008 at Downriver, chromium (Cr) levels in the #7 rough irrigated with city water exceeded the Model Toxics Control Act (MTCA) cleanup standards, but was within safe levels when measured at the end of the study. Arsenic (As) levels, not highlighted in 2008 (Phase II report), did exceed the MTCA standards in both years on #6 tee for both irrigation sources, but these levels did not change from year to year. At Qualchan the only heavy metal to exceed the MTCA standards was As on the newly built #16 tee, but it did not change from the beginning to the end of the study. Mercury (Hg) level was close to the MTCA limit in 2008 and slightly exceeded that limit in 2009 at the #7 rough irrigated with city water.

Soil physical properties:

An undisturbed soil core was taken on 15 May 2008 and compared to one taken on 15 Oct. 2009 to determine whether reuse water has an impact on soil physical properties. Samples for comparison were from Downriver #6 tee receiving city water and Downriver #6 tee receiving reuse water; Qualchan #16 fairway receiving pond water and Qualchan #16 fairway receiving reuse water. ISTRC SYSTEM™ BenchMarking of an undisturbed core sample was performed by the International Sports Turf Research Center (ISTRC), Inc. Discussions of the results of soil physical properties were provided by ISTRC (minor editing by WSU).

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Downriver #6 tee City Water:

As in 2008, there are several issues with the sand rootzone on #6 tee. Physically the sampled soil core has very poor infiltration/percolation rate and air porosity due to the combined impact of high OM and high amounts of fine and very fine sand that results in a rootzone mix that is highly susceptible to compaction (Table 5 and Appendix Tables 1 and 2). This also creates conditions that result in excessive water porosity and water holding in the rootzone. To sustain turfgrass growth on the tee it will be necessary to provide compaction relief by core aeration and topdress with an appropriate textured sand. This should increase air porosity and infiltration rate and lower water porosity and organic content of the rootzone.

Downriver #6 tee Reuse Water:

As expected this sample was very similar to the sample taken at the front of the tee receiving only city water (see above) for irrigation (Table 5 and Appendix Tables 1 and 2). One exception is that this sample has a much lower infiltration/percolation rate. This could be due to the fact the sample may have been taken in an area of higher traffic resulting in higher compaction. One would not suspect at this time, even though Na levels are higher where the reuse water is applied to the tee, that this would contribute significantly to additional soil compaction (Table 1). As mentioned above for #6 tee receiving city water, aeration and sand topdressing would definitely be necessary to relieve soil compaction.

Qualchan #16 fairway Pond Water:

The sample taken from the fairway receiving pond water for irrigation, has very poor soil physical properties. The soil has extremely low (sealed off) infiltration/percolation rates, very low air porosity, excessive water porosity and excessive to very high organic content in the top 2 in. (Table 6). This is an extremely 'thatchy' root zone with the majority roots buried in the top 2 inches of thatch. Root development has been confined to the top 1.5 inches. Couple this extremely 'thatchy' upper root zone with the subsoil (Table 6 and Appendix Table 4) nature of this soil beneath will create subsurface drainage that is virtually non-existent. If the water can not evaporate efficiently to remove excessive moisture this soil could become anaerobic. If this occurs the turf will die. In addition, this is not a good scenario if one wants to irrigate, especially with reuse water, because this will hasten the accumulation of salts on the soil surface and eventually affect turfgrass growth. It would be of great benefit to aggressively verticut and sand topdress this fairway. In addition, solid core or deep tine aeration would help as well.

Qualchan #16 fairway Reuse Water:

The site has the same amount of thatch as the #16 fairway reuse water site (see above) and very similar soil physical properties (Table 6). With similar soil physical properties between the two samples, it appears that reuse water does not impact these soil properties any more than

using pond water for irrigation. As mentioned above, for the pond water sample, the fairway would benefit greatly from aggressive cultural practices to remove thatch and improve subsurface infiltration/percolation.

The above soil physical property samples are of concern for turfgrass growth and management due to their low leaching potential, and will pose a problem if salts (especially Na) accumulate from the prolonged use of reuse water and can not be leached below the rootzone. This will be much less of a problem on sand-based greens and tees with adequate subsurface drainage.

Task 3. Water sampling and analysis.

The irrigation water samples were: Downriver city water, Qualchan pond water, and reuse water (from the City of Spokane water treatment plant) obtained from irrigation systems established at Qualchan and Downriver golf courses. The analysis of these water samples for irrigation suitability was conducted by Harris Laboratories.

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An extended heavy metal screen and mercury analysis on reuse and city and pond water was conducted by the University of Idaho Analytical Sciences Laboratory.

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Water samples for heavy metals were taken on 15 May, 17 Aug., and 15 Oct. 2009. The water samples were: Downriver city water and reuse water and Qualchan pond water and reuse water.

Results.

Irrigation suitability:

Downriver.

The irrigation suitability samples of reuse and city water at Downriver were taken three times in 2009 (15 May, 17 Aug., and 15 Oct.). The 'water characteristics' of reuse water and city water were different, with higher hardness and generally lower bicarbonate and carbonate levels in the reuse water compared to city water (Table 7). Both water sources had elevated hardness levels, which could be a possible problem. In addition, both water sources had similar pH levels, which were high and also could pose long-term problems.

Although still within satisfactory levels, reuse water compared to city water had several times higher levels of total soluble salts, EC, Na, Cl, and SAR. The only other parameter of concern was the low EC in city water, which may have an impact on soil structure. Not to be overlooked is the added benefit of reuse water which has higher levels of many essential plant nutrients compared to city water.

Qualchan.

The irrigation suitability samples of reuse and pond water at Qualchan were taken three times in 2009 (15 May, 17 Aug., and 15 Oct.) (Table 8). As one may expect, the 'water characteristics' and impact on the plant and soil are virtually the same as reported at Downriver (Table 7). Additionally, as seen at Downriver, are the higher levels of essential plant nutrients in reuse compared to pond water.

Overall, 'water characteristics' were of largest concern with both water sources. Each had similar pH levels, which were high and could pose possible problems. Each had elevated hardness levels that could pose possible problems. However, bicarbonates were higher in city and pond water compared to reuse water. Even though other irrigation suitability parameters that impact the turfgrass plant and soil were within the satisfactory range, reuse water levels were generally several times higher than city or pond water. Reuse water does have the benefit of providing higher levels of plant nutrients essential for plant growth compared to city or pond water.

Extended heavy metal screen and mercury analysis:

The heavy metal and Hg analysis for Downriver and Qualchan are presented in Tables 9 and 10, respectively. As seen in 2008, at both Downriver and Qualchan in 2009, the reuse water and the city or pond water were well below EPA recommended limits for heavy metals in reuse water for irrigation. With respect to heavy metals, these water sources do not pose any apparent irrigation problem. However, it is still important to continue monitoring for heavy metals wherever reuse water is used (Harivandi, 2004).

Task 4. Tissue testing.

Turfgrass leaf tissue samples were taken on 15 May, 15 Jun., 17 Aug., and 15 Oct. 2009 during the turfgrass growing season from each of the the ten golf course sites. Tissue samples were obtained from a mower basket following mowing of tees and greens by golf course personnel and from hand clipped samples obtained by WSU personnel from golf course fairway and rough sites. The samples were air dried and foreign debris and any fertilizer prills were removed by hand from the sample prior to shipping to Harris Laboratories for tissue analysis.

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Results.

The effect of reuse, city, or pond water on leaf tissue analysis at Downriver and Qualchan are listed in Tables 11 and 12, respectively. Differences due to levels below the normal range were minor and probably can be ignored, as low nutrient levels can be supplemented with fertilizers if warranted.

Tissue tests (Downriver).

Downriver #7 rough leaf tissue samples, in general, indicated higher and within normal ranges of nitrogen (N), P and K where reuse water was applied compared to city water (Table 11). Magnesium (Mg), Na, and sulfur (S) levels were similar and within normal ranges regardless of irrigation water source. Plants growing in the rough, tended to be high (above the normal range) in iron (Fe) where reuse water was applied compared to city water. Copper (Cu) and B levels were low. Levels above the normal range are not inherently detrimental to plants. Also, they may reflect a recent application of fertilizer if consistent between water sources.

Downriver #6 tee leaf tissue samples indicated only minor differences due to irrigation water source. Compared to city water, the reuse water tissue samples generally had higher N levels. As with the #7 rough samples, plants were high in Fe and low in Cu. Tissue levels of manganese (Mn) were also high for both irrigation water sources on #6 tee.

Tissue tests (Qualchan).

Qualchan #15 green tissue samples were fairly consistent between irrigation water sources. Regardless of water source, leaf tissue samples tended to be high in Fe, low in B and normal levels of Na (Table 12).

Qualchan #16 fairway reuse water tissue samples tended to be higher in N and K compared to pond water. Regardless of water source, Cu and B were below the normal range. Sodium levels were similar and within normal ranges for both water sources.

Tissue samples were very similar on #16 tee even with the drastic age difference between the reuse and pond irrigated tees. This suggests that very similar fertility programs are being used on these tees in 2009 as opposed to 2008 when the reuse tee was newly constructed and being grown in. If anything, the pond water tee has slightly higher N levels than the reuse water tee. As with the fairway and the green, Na levels were in the satisfactory range regardless of water source.

Task 5. Turfgrass evaluation.

The golf course sites were evaluated monthly (mid-May through mid-Oct. 2009) for turfgrass parameters by Washington State University turfgrass personnel.

The monthly turfgrass evaluations were:

Turfgrass quality visually evaluated 1-9; 9 = excellent turfgrass quality (Table 13).

Turfgrass color visually evaluated 1-9; 9 = healthy, dark green color (Table 14).

Chlorophyll index was measured with a CM1000 Chlorophyll Meter (Spectrum Technologies) in the field as a further indication of turfgrass color and health (Table 15).

Collection of data on additional turfgrass parameters, e.g., phytotoxicity, disease, etc. were not warranted during 2009.

Results.

Turfgrass quality (Downriver).

At Downriver, turfgrass quality of the #6 tee showed no irrigation water treatment differences throughout the season (Table 13). The visual turfgrass quality of the tee was highly consistent, receiving an above average turfgrass quality rating of 7 throughout most of the growing season.

At Downriver #7 rough, early in the season there was no difference in visual turfgrass quality due to source of irrigation water (Table 13). However, from 15 Jul. through 15 Oct. 2009 the area of the #7 rough receiving reuse water was consistently better than the area receiving city water. The magnitude of the difference was 3 units greater, so the turfgrass quality difference would be noticeable. This difference is most probably due to the location of the reuse water site that was located in a low, wet area of the rough creating better growing conditions.

Turfgrass quality (Qualchan).

The newly constructed #16 back tee receiving reuse irrigation water had a slightly higher, and more consistent, turfgrass quality throughout most of the summer compared to the older #16 forward tee receiving pond water (Table 13).

The #15 green was reconstructed in the fall 2008. Visual turfgrass quality ratings were the same regardless of water source used for irrigation in 2009.

Qualchan #16 fairway that received reuse water had slightly better turfgrass quality compared to the pond water site throughout the summer of 2009.

Turfgrass color (Downriver).

Turfgrass color of the #7 rough (Table 14) showed a similar trend as turfgrass quality ratings of the #7 rough discussed above (Table 13). Early in the season the turfgrass had similar color in both areas, but from July through October there was a large difference in turfgrass color. The area of #7 rough that received reuse irrigation water was consistently a darker green color than the area receiving city water. This area (where reuse water was applied) was also at the lowest part of the fairway and generally the soil was wetter, which contributed in some extent to better turfgrass growth than the area where city water was applied.

Downriver #6 tee showed no color differences during the rating period due to irrigation water source.

Turfgrass color (Qualchan).

Qualchan #16 back tee receiving reuse water, for the most part, had equal to or slightly better color than the older forward tee (Table 14).

Qualchan #15 green showed no difference in turfgrass color between irrigation water sources throughout the season.

Qualchan #16 fairway turfgrass color was slightly higher throughout the season for the fairway area that received reuse irrigation water. Again differences were small and would not be noticeable unless side-by-side comparisons of the turfgrass areas could be made.

Turfgrass chlorophyll index (Downriver).

Downriver #6 tee showed only minor differences, and inconsistent trends, due to irrigation water source for chlorophyll index throughout the 2009 season (Table 15).

Downriver #7 rough had chlorophyll index values that were consistently higher throughout the growing season for the rough area receiving reuse water (Table 15). This was similar to the visual rating for turfgrass color (Table 14). Overall the #7 rough area receiving reuse irrigation water had better color and probably healthier plants throughout the season as indicated by chlorophyll index and color ratings.

Turfgrass chlorophyll index (Qualchan).

Qualchan #16 back tees' chlorophyll index was higher in the area receiving reuse water except for May and August 2009 where the older forward tee had higher chlorophyll readings (Table 15). The chlorophyll index results (Table 15) are consistent with the visual ratings for turfgrass color (Table 14).

Qualchan #15 green chlorophyll index was very similar regardless of water source (Table 15) and consistent with visual color ratings (Table 14).

Qualchan #16 fairway chlorophyll index was consistently higher for the area receiving reuse irrigation water, which would indicate a slightly darker green and healthier turfgrass (Table 15).

Task 6. Fertilizer program nutrient balance.

Our original rationale was that a potential exists for nutrients to be added to the turfgrass areas receiving reuse irrigation water; therefore, it might be necessary to adjust the amount of nutrients (fertilizer) being applied by golf course personnel so that each site received the same amount of nutrients.

Results.

We reconsidered this task and decided it was not best to adjust fertility levels across water source treatment areas. The objectives of the study are to determine the effect of irrigation with reuse or city/pond water on several soil and turfgrass parameters under normal golf course maintenance and play. If supplemental nutrient applications were added, the long term effects and comparison of reuse to city/pond irrigation water would be masked by these additional applications. Also, since numerous elements were measured, balancing nutrients by golf course personnel would be extremely difficult, as most of these elements are not applied by golf course superintendents during routine golf course maintenance.

Task 7. Overall (Phase I, II, and III) project summary and conclusions.

We must caution that this study was not statistically replicated and should be viewed as a pilot study demonstration of the effects of using reuse water from the Spokane waste water treatment plant for irrigation on golf courses. The summary Tables 16 to 26 are numerical values averaged over each year (2008 or 2009).

Project Summary and Conclusions.

Soil nutrient levels were sometimes numerically higher for nitrate-N and K levels, but not always, in the soils irrigated with reuse water (Tables 16 and 17). Phosphorous was typically lower in soils irrigated with reuse water. Reuse water did increase soil Na levels from 2008 to 2009 and were much higher at each site compared to pond or city water used for irrigation (Tables 16 and 17). This is not surprising since Na levels were higher in reuse water (Tables 20 and 21). It would be important to know to what extent continued use of reuse water would have on soil Na levels at these sites. The SAR, although generally satisfactory, was higher in the reuse irrigation water. This too would indicate a potential problem with long-term use of reuse water. Soil salinity (EC) and CEC were not affected by using reuse water at either site (Table 16 and 17). Boron levels were slightly higher where reuse water was used; however, only on #7 rough at Downriver was it marginally high and could be a future concern. Boron is of concern because small amounts can be phytotoxic to plants; however, more so to ornamentals than turfgrasses.

Soil physical properties of #6 tee at Downriver and #16 fairway at Qualchan raise the issue of the soil types at these sites (See Task 2. Soil Physical Properties). If one uses reuse water for turf irrigation are the soil suitable? The samples from these two sites indicate problems with compaction, poor subsurface drainage, excessive water holding, and high to excessive OM content. The #6 tee was constructed with a sand rootzone over native soil. Unfortunately, the sand used to construct the tee rootzone had high amounts of fine to very fine sand (Appendix Tables 1 and 2), which contributed to the problems stated above. The #16 fairway at Qualchan, which is native soil, has an excessively high OM content and a soil beneath the thatch layer that does not allow for effective water infiltration. Cultural techniques such as core aeration, verticutting, and sand topdressing using an appropriate textured sand should improve many of the soil physical parameters outlined in Tables 5 and 6. At this time it is difficult to see any effect of reuse water, compared to city or pond water, on soil physical properties. As a note, the native soils at both of these golf courses, a gravelly sandy loam (Downriver) or sandy loam (Qualchan) should provide good subsurface drainage, which is a plus if reuse water is used for irrigating these golf courses in the native soil areas (fairways and roughs) that comprises the vast majority of turfgrass acreage on these courses. If reuse water is used, poorly drained areas should be identified and appropriate cultural methods used to correct poor subsurface drainage and excessive thatch (OM content) build up.

The use of reuse water did not affect any of the soil heavy metal levels during the two years of this study (Tables 18 and 19). This is not surprising since heavy metal levels in the reuse water were all well below the EPA recommended limits (Tables 10 and 11 [Phase II report] and Tables 9 and 10 [Phase III report]).

The water characteristics of reuse water were, for the most part, very similar to city water at Downriver (Table 20); however, high pH and hardness levels could pose a problem. At Qualchan, a sample taken on 15 Oct. 2008 resulted in very high levels of several irrigation suitability parameters (Phase II report, Table 7). It appears that there may have been a sampling error at Qualchan on this date, since this sample's values fall far out of line with any of the other samples taken. If one factors out this one sample at Qualchan, the irrigation suitability of reuse

water at both sites, in general, had levels of EC (soluble salts), total soluble salts, Na, Cl, and SAR that were several times higher than the pond or city water used for irrigation (Tables 20 and 21). Even though these levels were higher for reuse water, they were within satisfactory limits. As mentioned above when discussing soil nutrients, these higher levels could create potential problems with prolonged use over time. For example, although not reflected in soil EC, EC in reuse water was higher compared to city or pond water and within satisfactory range; however, its long term use may result in adverse salt build up in the soil. A benefit from irrigating with reuse water is the higher levels of many essential plant nutrients that would be applied to the turf, which may reduce, to some extent, the amount of fertilizer used at these golf courses. However, the daily application of nutrients to a golf course is not the normal practice. The constant application of nutrients when turfgrass growth is not desired may not be sound management. Also, several turfgrass diseases are favored by the application of plant nutrients (primarily N); thus, nutrient application during a disease outbreak may be undesirable from a turfgrass management perspective.

Leaf tissue analysis at each golf course site showed, in general, higher levels of N, P, and K where reuse water was applied compared to city or pond water (Tables 22 and 23). As mentioned above, higher levels of leaf tissue nutrients may, or may not be bad, but one may need to factor in the amount of essential plant nutrients added by reuse water irrigation and adjust fertilization accordingly. Therefore, one must carefully monitor the amount of reuse water applied and the essential plant nutrient concentrations to determine the amount of plant nutrients being applied.

In general, there were no visible adverse effects to turfgrass quality or color where reuse water was applied to any of the five reuse water sites in this study (Tables 24 and 25). There were some minor visual differences between reuse and city or pond water sites favoring reuse water, but these are most probably due to factors other than the type of irrigation water used (such as, the new #16 back tee vs. the established older #16 forward tee at Qualchan, and #7 rough where the reuse water site was in an area that was lower and wetter compared to where the city water was applied). Chlorophyll index readings confirmed, for the most part, visual color ratings at each of the 10 sites (Tables 25 and 26).

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Table 1. The effect of reuse and city water, used to irrigate turfgrass, on basic soil test results at Downriver Golf Course in 2009.

Basic soil test (Downriver GC)														Interpretation			
Units	7 Rough						6 Tee						Analysis Method	Interpretation			
	Reuse Water			City Water			Reuse Water			City Water				Below	Above		Unsatisfactory
	5/15	8/17	10/15	5/15	8/17	10/15	5/15	8/17	10/15	5/15	8/17	10/15		Optimum Range	Optimum Range	Optimum Range	
pH		6.8	6.7	7.0	6.7	6.8	7.1	7.4	7.4	7.2	7.2	7.1	7.0				< 4.5 & > 8.5
Organic Matter	%	12.5	9.9	6.3	24.7	17.1	5.7	2.1	1.9	1.7	1.8	1.9	2.1		1 - 10		> 10
NO ₃ -N	ppm	29	24	21	13	16	31	5	7	5	4	7	2				
NH ₄ -N	ppm																
Phosphorous	ppm	14	21	18	11	11	18	85	45	271	59	193	217	Bicarb	12 - 15		
Potassium	ppm	166	179	164	150	147	156	159	160	137	112	128	103	Bicarb	165 - 200		
SO ₄ -S	ppm	11	26	18	8	15	18	8	18	17	6	13	12		14 - 20		
Boron	ppm	0.5	0.8	0.5	0.4	0.5	0.7	0.6	0.5	0.3	0.4	0.5	0.2		0.3 - 0.5		
EC (SS)	mmho/cm	0.35	0.42	0.37	0.31	0.36	0.41	0.18	0.27	0.24	0.14	0.18	0.14	Sat. Ext.	< 0.75		> 2.5
Zinc	ppm	2.7	3.0	2.4	2.3	1.3	2.4	4.8	4.0	4.9	3.7	2.9	3	DPTA	0.8 - 1.5		
Calcium	ppm	1787	1932	1811	2791	2786	1730	1181	1259	1173	1123	1170	1074	Sat. Ext.			
Magnesium	ppm	317	385	358	502	529	342	109	137	135	78	99	99	Sat. Ext.			
Sodium	ppm	62	112	106	16	35	107	44	108	100	8	17	16	Sat. Ext.			
SAR	meq/L														< 4.0		> 9.0
CEC	meq/100g	12.3	13.8	12.9	18.6	18.9	12.4	7.4	8.3	7.8	6.6	7.1	6.5				

Table 2. The effect of reuse and pond water, used to irrigate turfgrass, on basic soil test results at The Creek at Qualchan Golf Course in 2009.

Basic soil test (The Creek at Qualchan GC)																		Interpretation						
	Units	15 Green*						16 fairway						16Tee						Analysis Method	Interpretation			
		Reuse water			Pond water			Reuse water			Pond water			Reuse water**			Pond water				Below	Above		
		5/15	8/17	10/15	5/15	8/17	10/15	5/15	8/17	10/15	5/15	8/17	10/15	5/15	8/17	10/15	5/15	8/17	10/15		Optimum Range	Optimum Range	Optimum Range	Unsatisfactory
pH		7.4	7.8	7.8	7.7	7.5	7.9	6.9	6.8	6.6	6.7	6.9	6.8	7.8	7.9	7.7	6.8	7.0	7.0			6.0 - 7.0		< 4.5 & > 8.5
Organic Matter	%	1.1	0.8	0.7	0.9	0.9	0.6	3.4	2.9	2.7	6.5	5.8	2.4	0.6	0.6	0.6	4.9	4.9	3.8			1 - 10		> 10
NO ₃ -N	ppm	31	13	9	22	14	4	10	14	11	3	6	5	2	3	3	5	5	3					
NH ₄ -N	ppm																							
Phosphorous	ppm	12	8	13	8	11	8	15	11	15	26	23	22	11	6	19	25	22	21	Bicarb		12 - 15		
Potassium	ppm	142	149	147	115	164	112	138	115	131	172	188	169	54	49	32	139	139	107	Bicarb		165 - 200		
SO ₄ -S	ppm	25	10	5	12	6	4	4	15	9	8	14	12	2	8	12	9	12	6			14 - 20		
Boron	ppm	0.4	0.4	0.1	0.3	0.3	0.1	0.6	0.5	0.3	0.4	0.4	0.2	0.3	0.4	0.2	0.4	0.4	0.2			0.3 - 0.5		
EC (SS)	mmho/cm	0.35	0.25	0.22	0.27	0.23	0.17	0.20	0.27	0.24	0.19	0.24	0.21	0.11	0.16	0.18	0.19	0.21	0.16	Sat. Ext.		< 0.75		> 2.5
Zinc	ppm	1.9	1.4	1.0	1.0	1.0	0.6	2.2	1.6	1.3	5.2	4.0	2.1	0.4	0.2	0.4	5.8	5.4	3.9	DPTA		0.8 - 1.5		
Calcium	ppm	1505	1491	1370	1410	1556	1379	1265	1318	1221	1456	1674	1286	646	662	567	1484	1498	1172	Sat. Ext.				
Magnesium	ppm	209	249	254	267	253	267	322	333	316	388	467	401	114	120	115	285	307	297	Sat. Ext.				
Sodium	ppm	27	47	54	16	21	20	32	54	60	14	22	25	26	73	95	13	21	11	Sat. Ext.				
SAR																						< 4.0		> 9.0
CEC	meq/100g	9.7	10.1	9.6	9.6	10.4	9.5	9.5	9.9	9.3	11.0	12.8	10.3	4.4	4.8	4.3	10.2	10.5	8.7					

*Green reconstructed in Fall 2008 with a new sand base and sod from the old green. Soil test reflects the new sand that was used to construct the green.

**Reuse water tee finished construction in June 2008.

Table 3. Final (15 Oct. 2009) soil heavy metal levels at Downriver Golf Course.

Analyte	Soil heavy metal levels (ppm)				MTCA Cleanup Regulations*			
	7 Rough		6 Tee		(Ecological Indicator Soil Concentrations for Protection of Terrestrial Plants) (ppm)	Detect Limit (ppm)	Analysis Method	Prep Method
	Reuse	City	Reuse	City				
Beryllium	0.55	0.54	0.37	0.37	10	0.02	ICP-MS	3050B Digest
Chromium	26	23	11	12	42	0.38	ICP-MS	3050B Digest
Cobalt	6	6	4	4	20	0.02	ICP-MS	3050B Digest
Nickel	13	13	9	10	30	0.06	ICP-MS	3050B Digest
Copper	15	15	20	15	100	0.06	ICP-MS	3050B Digest
Arsenic	6	6	13	12	10	0.38	ICP-MS	3050B Digest
Selenium	<0.38	<0.38	<0.38	<0.38	1	0.38	ICP-MS	3050B Digest
Molybdenum	1.00	1.00	0.49	0.43	2	0.02	ICP-MS	3050B Digest
Silver	0.09	0.11	0.68	0.42	2	0.08	ICP-MS	3050B Digest
Cadmium	0.33	0.33	0.15	0.13	4	0.04	ICP-MS	3050B Digest
Antimony	<0.38	<0.38	<0.38	<0.38	5	0.38	ICP-MS	3050B Digest
Barium	130	120	79	73	500	0.04	ICP-MS	3050B Digest
Thallium	0.18	0.19	0.14	0.13	1	0.06	ICP-MS	3050B Digest
Lead	43	46	12	12	50	0.04	ICP-MS	3050B Digest
Mercury	0.082	0.340	0.040	0.032	0.3	0.008	CVAFS	Nitric/HCl Digest

*Model Toxics Control Act (MTCA) compiled by the Washington State Department of Ecology Toxics Cleanup Program. (WAC 173-340-900).

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Website: <http://www.ecy.wa.gov/pubs/9406.pdf>

Exceeds MTCA levels for cleanup.

Table 4. Final (15 Oct. 2009) soil heavy metal levels at The Creek at Qualchan Golf Course.

Analyte	Soil heavy metal levels (ppm)						MTCA Cleanup Regulations (Ecological Indicator Soil Concentrations for Protection of Terrestrial Plants)** (ppm)			
	15 Green*		16 Fairway		16 Tee		Detect Limit (ppm)	Analysis Method	Prep Method	
	Reuse	Pond	Reuse	Pond	Reuse	Pond				
Beryllium	0.26	0.25	0.46	0.5	0.39	0.51	10	0.02	ICP-MS	3050B Digest
Chromium	7	7	14	14	10	14	42	0.38	ICP-MS	3050B Digest
Cobalt	5	5	7	7	4	7	20	0.02	ICP-MS	3050B Digest
Nickel	6	5	12	12	9	12	30	0.06	ICP-MS	3050B Digest
Copper	13	12	11	12	10	13	100	0.06	ICP-MS	3050B Digest
Arsenic	2	2	7	9	14	8	10	0.38	ICP-MS	3050B Digest
Selenium	<0.38	<0.38	<0.38	<0.38	<0.38	<0.38	1	0.38	ICP-MS	3050B Digest
Molybdenum	0.26	0.24	0.51	0.49	0.39	0.47	2	0.02	ICP-MS	3050B Digest
Silver	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	2	0.08	ICP-MS	3050B Digest
Cadmium	0.44	0.06	0.10	0.17	0.07	0.27	4	0.04	ICP-MS	3050B Digest
Antimony	<0.38	<0.38	<0.38	<0.38	<0.38	<0.38	5	0.38	ICP-MS	3050B Digest
Barium	33	33	95	100	66	100	500	0.04	ICP-MS	3050B Digest
Thallium	0.08	0.07	0.15	0.15	0.14	0.17	1	0.06	ICP-MS	3050B Digest
Lead	3	4	10	11	9	11	50	0.04	ICP-MS	3050B Digest
Mercury	<.012	<.012	<.012	<.012	<.012	<.012	0.3	0.008	CVAFS	Nitric/HCl Digest

*Green reconstructed Fall 2008 with a new sand base and sod from the old green. Green was resampled for heavy metals on 10/15/08.

**Model Toxics Control Act (MTCA) compiled by the Washington State Department of Ecology Toxics Cleanup Program. (WAC 173-340-900). Oct 12, 2007. Page 247.

Website: <http://www.ecy.wa.gov/pubs/9406.pdf>

Exceeds MTCA levels for cleanup.

Table 5. Initial (15 May 2008) and final (15 Oct. 2009) soil properties at Downriver Golf Course #6 tee.

Downriver Golf Course #6 tee						Interpretation				
	Units	Reuse water		Pond water		Sealed	Very	Optimum	Very	
		2008	2009	2008	2009	off	low	range	high	Excessive
Infiltration rate	in./hr	1.23	0.04	0.27	0.62			4 - 10		
Subsurface air capacity (air porosity)	%	13.5	7.7	12.2	10.9			~ 18		
Water porosity (capillary)	%	37	41	37	42			~ 20		
Bulk density	g/cc	1.38	1.41	1.42	1.31			1.35 - 1.5		
Water holding	%	27.0	29.3	26.4	32.3			~ 18		
Organic content (1/4 to 1 in.)	%	2.58	3.53	3.00	4.39			1.5 - 2.5		
Organic content (1 to 2 in.)	%	2.58	2.44	2.59	2.56			1.0 - 2.0		
Organic content (2 to 3 in.)	%	3.12	2.15	2.40	2.17			0.5 - 2.0		
Organic content (3 to 4 in.)	%	2.87	2.40	2.44	2.14			0.5 - 1.5		
Root mass	in.	1/2 in.	5/8 in.	1/2 in.*	5/8 in.*			> 1/2 in.		
Feeder roots	in.	sparse at 3 in.	< 3 in.	Med. at 3 in.**	< 3 in.	> 3.5 in. - Medium density				

*Rooting in buried thatch.

**Medium at 3 in. (very good).

Table 6. Initial (15 May 2008) and final (15 Oct. 2009) soil properties at The Creek at Qualchan Golf Course #16 fairway.

		The Creek at Qualchan #16 fairway				Interpretation				
		Reuse water		Pond water		Sealed	Very	Optimum	Very	
	Units	2008	2009	2008	2009	Off	low	range	high	Excessive
Infiltration rate	in./hr	0.81	0.15	0.15	0.01			2 - 6		
Subsurface air capacity (air porosity)	%	17.0	11.8	10.4	5.8			12 - 18		
Water porosity (capillary)	%	48	51	66	58			<30		
Bulk density	g/cc	1.02	1.13	0.71	1.00			1.2 - 1.5		
Water holding	%	47.2	45.2	92.4	58.1			<25		
Organic content (1/4 to 1 in.)	%	6.68	6.20	7.92	5.78			1.5 - 2.5		
Organic content (1 to 2 in.)	%	4.56	4.20	6.76	3.52			1.0 - 2.0		
Organic content (2 to 3 in.)	%	1.50	1.46	2.94	1.51			0.5 - 2.0		
Organic content (3 to 4 in.)	%	0.98	0.70	0.89	0.69			0.5 - 1.5		
Root mass	in.	5/8 in.	3/8 in.	5/8 in.	5/8 in.			> 1/2 in.		
Feeder roots	in.	sparse at 3 in.	sparse at 3 in.	sparse at 3 in.	< 3 in.			> 3.5 in. - Medium density		

Table 7. Irrigation suitability of reuse water from the Spokane waste water treatment plant and city water at Downriver Golf Course in 2009.

		Irrigation suitability (Downriver GC)						Interpretation			
		Units	Reuse water			City water			Satisfactory	Possible problem	Probable problem
			5/15	8/17	10/15	5/15	8/17	10/15			
Water Characteristics	pH		7.9	7.8	7.4	8.0	8.0	7.7	5.5 - 7.5	4.5 - 5.5 & 7.5 - 8.5	< 4.5 & > 8.5
	Hardness		210	221	208	178	165	180	0 - 125	126 - 245	>245
	Bicarbonate	ppm	107	95	85	168	149	188	0 - 111	112 - 525	>525
	Carbonate	ppm	2.40	0.01	0.00	4.80	0.01	2.40	0 - 12	13 - 62	>62
Impact on general growth	EC	mmhos/cm	0.67	0.71	0.72	0.32	0.28	0.33	0 - 0.75	0.75 - 3.0	>3.0
	Total Soluble Salts	ppm	429	454	461	205	179	211	0 - 480	481 - 1950	>1950
Impact from root contact	Sodium	meq/l	2.31	2.62	1.69	0.20	0.19	0.13	0 - 2.9	3.0 - 9.0	>9.0
	Chloride	ppm	66.3	73.8	66.5	6.5	4.9	5.9	0 - 140	141 - 360	>360
	Boron	ppm	0.13	0.02	0.15	0.01	0.02	0.01	0 - 0.5	0.6 - 2.0	>2.0
Impact from foliage contact	Sodium	ppm	53.2	60.3	38.9	4.5	4.4	3.1	0 - 70	71 - 210	>210
	Chloride	ppm	66.3	73.8	66.5	6.5	4.9	5.9	0 - 100	101 - 350	>350
Impact on soil structure	SAR	meq/l	2.78	3.01	1.91	0.29	0.27	0.20	0 - 6.0	6.1 - 9.0	> 9.0
	EC	mmhos/cm	0.67	0.71	0.72	0.32	0.28	0.33	> 0.51	< 0.50	
	Total Soluble Salts	ppm	429	454	461	205	179	211			
Plant Nutrients	Nitrate (NO ₃ -N)	ppm	19.27	21.46	22.81	1.20	0.01	1.18			
	Phosphate (PO ₄)	ppm	0.96	0.44	0.01	0.35	0.01	0.01			
	Potassium (K)	ppm	10.9	12.6	12.8	2.5	4.5	2.9			
	Magnesium (Mg)	ppm	23.4	25.5	22.7	18.4	16.2	18.4			
	Calcium (Ca)	ppm	45.9	45.7	46.2	41.2	39.2	41.9			
	Sulfate (SO ₄)	ppm	60.5	70.0	82.0	18.1	16.0	18.0			
	Manganese (Mn)	ppm	0.00	0.01	0.01	0.00	0.01	0.01			
	Iron (Fe)	ppm	0.00	0.01	0.01	0.01	0.01	0.01			
	Boron (B)	ppm	0.13	0.16	0.15	0.01	0.02	0.01			

Table 8. Irrigation suitability of reuse water from the Spokane waste water treatment plant and water pumped from an irrigation pond at The Creek at Qualchan Golf Course in 2009.

		Irrigation suitability (The Creek at Qualchan GC)							Interpretation		
		Units	Reuse water			Pond water			Satisfactory	Possible problem	Probable problem
			5/15	8/17	10/15	5/15	8/17	10/15			
Water Characteristics	pH		7.9	7.8	7.6	7.9	7.9	8.0	5.5 - 7.5	4.5 - 5.5 & 7.5 - 8.5	< 4.5 & > 8.5
	Hardness		208	222	212	161	180	152	0 - 125	126 - 245	>245
	Bicarbonate	ppm	124	105	81	149	163	149	0 - 111	112 - 525	>525
	Carbonate	ppm	2.40	0.01	0.00	4.80	2.40	2.40	0 - 12	13 - 62	>62
Impact on general growth	EC	mmhos/cm	0.32	0.71	0.70	0.29	0.31	0.28	0 - 0.75	0.75 - 3.0	>3.0
	Total Soluble Salts	ppm	205	454	448	186	198	179	0 - 480	481 - 1950	>1950
Impact from root contact	Sodium	meq/l	2.29	2.81	1.69	0.18	0.20	0.13	0 - 2.9	3.0 - 9.0	>9.0
	Chloride	ppm	65.1	81.3	67.9	6.5	6.0	6.5	0 - 140	141 - 360	>360
	Boron	ppm	0.13	0.16	0.15	0.01	0.02	0.01	0 - 0.5	0.6 - 2.0	>2.0
Impact from foliage contact	Sodium	ppm	52.6	64.7	38.8	4.1	4.7	3.1	0 - 70	71 - 210	>210
	Chloride	ppm	65.1	81.3	67.9	6.5	6.0	6.5	0 - 100	101 - 350	>350
Impact on soil structure	SAR	meq/l	2.86	3.30	1.87	0.26	0.29	0.20	0 - 6.0	6.1 - 9.0	> 9.0
	EC	mmhos/cm	0.32	0.71	0.70	0.29	0.31	0.28	> 0.51	< 0.50	
	Total Soluble Salts	ppm	205	454	448	186	198	179			
Plant Nutrients	Nitrate (NO ₃ -N)	ppm	19.07	23.68	21.05	0.55	0.87	0.62			
	Phosphate (PO ₄)	ppm	0.42	0.15	0.01	0.11	0.01	0.01			
	Potassium (K)	ppm	10.9	17.5	12.6	2.7	5.8	2.9			
	Magnesium (Mg)	ppm	23.3	25.5	23.2	15.7	18.4	15.6			
	Calcium (Ca)	ppm	44.8	46.8	46.6	38.5	41.7	35.2			
	Sulfate (SO ₄)	ppm	60.6	69.9	83.9	15.8	17.9	14.8			
	Manganese (Mn)	ppm	0.00	0.01	0.01	0.00	0.01	0.01			
	Iron (Fe)	ppm	0.00	0.05	0.01	0.01	0.01	0.01			
	Boron (B)	ppm	0.13	0.16	0.15	0.01	0.02	0.01			

Table 9. Heavy metal levels in irrigation water at Downriver Golf Course in 2009.

Analyte	Irrigation water heavy metal levels (ppb)					
	Reuse water			City water		
	5/15	8/17	10/15	5/15	8/17	10/15
Beryllium	< 0.13	< 0.13	< 0.13	< 0.13	< 0.13	< 0.13
Chromium	< 1	< 1	< 1	< 1	< 1	< 1
Cobalt	< 0.25	< 0.25	< 0.25	< 0.25	< 0.25	< 0.25
Nickel	1.4	1.1	0.75	< 0.5	< 0.5	< 0.5
Copper	6.7	5	7.3	< 0.5	0.62	3.4
Arsenic	0.89	2.8	0.56	3	2.8	3.1
Selenium	< 1	< 1	< 1	< 1	< 1	< 1
Molybdenum	2	< 1	1.8	1.5	< 1	1.3
Silver	< 0.25	< 0.25	< 0.25	< 0.25	< 0.25	< 0.25
Cadmium	< 0.25	< 0.25	< 0.25	< 0.25	< 0.25	< 0.25
Barium	18	21	25	29	25	28
Lead	< 0.25	< 0.25	3.3	< 0.25	< 0.25	0.35
Mercury	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Vanadium	0.31	0.48	< 0.25	< 0.25	< 0.25	< 0.25
Manganese	0.45	0.45	0.32	< 0.25	< 0.25	< 0.25
Zinc	340	65	65	210	35	36

EPA* Recommended Limits for Heavy Metals in Reuse Water for Irrigation Long term use (ppb)	EPA* Recommended Limits for Heavy Metals in Reuse Water for Irrigation Short term use (ppb)	Detect Limit (ppb)	Analysis Method	Prep Method
100	500	0.13	ICP-MS	
100	1000	1	ICP-MS	
50	5000	0.25	ICP-MS	
200	2000	0.5	ICP-MS	
200	5000	0.5	ICP-MS	
100	2000	0.5	ICP-MS	
20	20	1	ICP-MS	
10	50	1	ICP-MS	
		0.25	ICP-MS	
10	50	0.25	ICP-MS	
		0.5	ICP-MS	
5000	10000	0.25	ICP-MS	
		0.05	CVAFS	BrCl Digest
100	1000	0.25	ICP-MS	
200	10000	0.25	ICP-MS	
2000	10000	2.5	ICP-MS	

*EPA Guidelines for Water Reuse. EPA/625/R-04/108. Sept. 2004. Page 25.

Website: <http://www.epa.gov/ord/NRMRL/pubs/625r04108/625r04108.pdf>

Table 10. Heavy metal levels in irrigation water at The Creek at Qualchan Golf Course in 2009.

Irrigation water heavy metal levels (ppb)						
Analyte	Reuse water			Pond water		
	5/15	8/17	10/15	5/15	8/17	10/15
Beryllium	< 0.13	< 0.13	< 0.13	< 0.13	< 0.13	< 0.13
Chromium	< 1	< 1	< 1	< 1	< 1	< 1
Cobalt	< 0.25	< 0.25	< 0.25	< 0.25	< 0.25	< 0.25
Nickel	1.1	1.2	0.84	< 0.5	< 0.5	< 0.5
Copper	7.7	5.4	5.9	3.3	4.2	1.8
Arsenic	0.76	0.9	0.57	2.3	2.6	2.9
Selenium	< 1	< 1	< 1	< 1	< 1	< 1
Molybdenum	1.9	< 1	2.2	1.2	< 1	1.3
Silver	< 0.25	< 0.25	< 0.25	< 0.25	< 0.25	< 0.25
Cadmium	< 0.25	< 0.25	< 0.25	< 0.25	< 0.25	< 0.25
Barium	18	21	24	29	30	32
Lead	< 0.25	< 0.25	< 0.25	< 0.25	< 0.25	< 0.25
Mercury	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Vanadium	0.48	0.47	< 0.25	< 0.25	< 0.25	< 0.25
Manganese	7.1	1.4	2.9	0.63	< 0.25	< 0.25
Zinc	140	57	60	120	55	9.6

EPA* Recommended Limits for Heavy Metals in Reuse Water for Irrigation Long term use (ppb)	EPA* Recommended Limits for Heavy Metals in Reuse Water for Irrigation Short term use (ppb)	Detect Limit (ppb)	Analysis Method	Prep Method
100	500	0.13	ICP-MS	
100	1000	1	ICP-MS	
50	5000	0.25	ICP-MS	
200	2000	0.5	ICP-MS	
200	5000	0.5	ICP-MS	
100	2000	0.5	ICP-MS	
20	20	1	ICP-MS	
10	50	1	ICP-MS	
		0.25	ICP-MS	
10	50	0.25	ICP-MS	
		0.5	ICP-MS	
5000	10000	0.25	ICP-MS	
		0.05	CVAFS	BrCl Digest
100	1000	0.25	ICP-MS	
200	10000	0.25	ICP-MS	
2000	10000	2.5	ICP-MS	

*EPA Guidelines for Water Reuse. EPA/625/R-04/108. Sept. 2004. Page 25.
 Website: <http://www.epa.gov/ord/NRMRL/pubs/625r04108/625r04108.pdf>

Table 11. The effect of reuse and city water on leaf tissue analysis of turfgrass at Downriver Golf Course in 2009.

Turfgrass leaf tissue analysis (Downriver GC)

	Units	7 Rough								6 Tee								Below	Above	
		Reuse water				City water				Reuse water				City water				Normal	Normal	Normal
		5/15	6/15	8/17	10/15	5/15	6/15	8/17	10/15	5/15	6/15	8/17	10/15	5/15	6/15	8/17	10/15	Range	Range	Range
Nitrogen	%	3.99	4.17	4.12	4.33	3.48	3.62	2.83	2.69	3.86	5.16	4.28	4.71	4.00	3.75	3.66	2.85		3.90 - 4.50	
Phosphorous	%	0.44	0.33	0.38	0.34	0.31	0.23	0.31	0.25	0.41	0.46	0.40	0.51	0.41	0.36	0.41	0.38		0.29 - 0.50	
Potassium	%	3.20	2.67	3.14	2.75	2.77	2.47	2.19	2.37	2.25	2.98	2.33	2.72	2.10	2.26	2.58	2.02		2.49 - 3.50	
Magnesium	%	0.24	0.29	0.28	0.28	0.25	0.27	0.26	0.27	0.34	0.24	0.23	0.22	0.30	0.27	0.21	0.35		0.24 - 0.50	
Calcium	%	0.54	0.46	0.38	0.43	0.49	0.43	0.38	0.51	0.52	0.38	0.33	0.47	0.46	0.42	0.34	0.67		0.49 - 0.75	
Sodium	%	0.10	0.09	0.10	0.15	0.07	0.01	0.01	0.02	0.10	0.07	0.11	0.12	0.07	0.01	0.02	0.03		0.01 - 0.16	
Sulfur	%	0.30	0.38	0.40	0.37	0.21	0.31	0.33	0.29	0.29	0.38	0.32	0.38	0.23	0.24	0.29	0.26		0.25 - 0.40	
Zinc	ppm	29	32	46	38	25	28	37	36	49	48	47	45	55	38	43	41		40 - 60	
Manganese	ppm	40	32	36	36	35	30	30	26	147	102	110	68	140	138	147	160		41 - 80	
Copper	ppm	7	10	7	5	4	6	6	6	10	10	9	11	10	9	9	11		15 - 20	
Iron	ppm	429	140	214	497	170	125	136	289	4335	687	1100	490	3746	2172	551	4109		125 - 175	
Boron	ppm	9	10	7	7	7	7	5	5	19	14	14	9	15	11	9	16		20 - 40	
Molybdenum	ppm																			
Aluminum	ppm	374	61	143	414	117	57	59	171	2629	380	532	247	2350	1182	162	2395			

Table 12. The effect of reuse and city water on leaf tissue analysis of turfgrass at The Creek at Qualchan Golf Course in 2009.

Turfgrass leaf tissue analysis (The Creek at Qualchan GC)

	Units	15 Green*								16 fairway								16 Tee								Below	Above			
		Reuse water				Pond water				Reuse water				Pond water				Reuse water**				Pond water				Normal	Normal	Normal		
		5/15	6/15	8/17	10/15	5/15	6/15	8/17	10/15	5/15	6/15	8/17	10/15	5/15	6/15	8/17	10/15	5/15	6/15	8/17	10/15	5/15	6/15	8/17	10/15	5/15	6/15	8/17	10/15	Range
Nitrogen	%	4.74	5.94	5.52	4.78	4.21	5.63	5.29	4.33	3.37	4.14	4.63	3.97	3.25	3.84	3.45	2.75	3.25	4.60	3.74	4.11	5.35	4.44	4.40	4.47		3.90 - 4.50			
Phosphorous	%	0.48	0.58	0.67	0.46	0.45	0.54	0.63	0.42	0.46	0.37	0.43	0.34	0.44	0.29	0.45	0.23	0.42	0.37	0.40	0.31	0.42	0.40	0.56	0.37		0.29 - 0.50			
Potassium	%	1.89	2.62	2.83	2.07	1.88	2.34	2.81	1.76	2.91	2.87	2.98	2.43	2.11	2.65	2.28	1.99	2.48	3.07	2.88	2.21	2.14	2.43	2.83	2.06		2.49 - 3.50			
Magnesium	%	0.23	0.32	0.26	0.23	0.25	0.31	0.25	0.23	0.25	0.30	0.26	0.25	0.23	0.30	0.28	0.21	0.25	0.25	0.24	0.22	0.26	0.31	0.32	0.24		0.24 - 0.50			
Calcium	%	0.44	0.56	0.35	0.52	0.43	0.54	0.38	0.50	0.37	0.44	0.28	0.35	0.44	0.41	0.31	0.42	0.51	0.40	0.30	0.38	0.47	0.45	0.41	0.49		0.50 - 0.75			
Sodium	%	0.09	0.05	0.04	0.06	0.08	0.04	0.02	0.04	0.09	0.04	0.04	0.08	0.07	0.01	0.01	0.02	0.10	0.05	0.07	0.02	0.07	0.01	0.01	0.01		0.01 - 0.16			
Sulfur	%	0.34	0.49	0.48	0.43	0.31	0.44	0.46	0.34	0.29	0.40	0.45	0.36	0.23	0.35	0.31	0.24	0.31	0.40	0.33	0.31	0.24	0.39	0.43	0.34		0.26 - 0.40			
Zinc	ppm	67	78	80	57	66	71	74	50	47	46	52	36	37	36	41	24	29	46	45	39	35	51	57	39		40 - 60			
Manganese	ppm	101	77	58	53	96	85	73	60	73	55	41	31	116	92	54	41	99	194	160	73	146	81	47	50		41 - 80			
Copper	ppm	20	23	12	8	17	22	13	9	8	11	8	5	7	7	8	5	6	8	8	7	8	10	11	8		15 - 20			
Iron	ppm	3872	273	222	573	3506	544	950	1041	241	136	173	325	328	377	320	337	436	237	412	653	370	221	281	495		125 - 175			
Boron	ppm	16	14	8	10	15	12	9	9	11	9	7	7	9	8	6	4	13	17	20	10	12	8	5	5		20 - 40			
Molybdenum	ppm																													
Aluminum	ppm	961	367	48	256	1202	429	68	411	399	44	55	161	161	175	148	157	244	88	151	230	183	87	118	230					

*Green reconstructed in Fall 2008 with a new sand base and sod from the old green.

**Reuse water tee finished construction in June 2008.

Table 13. The effect of reuse and conventional irrigation water on visual turfgrass quality at The Creek at Qualchan and Downriver Golf Courses in 2009.

Golf Course	Area	Irrigation Source	Turfgrass quality*					
			5/15	6/15	7/15	8/17	9/15	10/15
Qualchan	16 Tee**	Reuse	5	7	7	6	7	7
	16 Tee	Pond	5	6	7	6	7	6
	15 Green***	Reuse	6	7	7	6	7	7
	15 Green***	Pond	6	7	7	6	7	7
	16 Fairway	Reuse	7	7	7	8	8	7
	16 Fairway	Pond	5	6	6	7	7	6
Downriver	6 Tee	Reuse	6	7	7	7	7	7
	6 Tee	City	6	7	7	7	7	7
	7 Rough	Reuse	7	6	8	8	8	7
	7 Rough	City	6	6	5	5	5	4

*Turfgrass quality rated on a scale of 1 to 9 with 9 = excellent turf quality.

**16 Tee irrigated with reuse water constructed June 2008.

***15 Green was reconstructed in fall 2008.

Table 14. The effect of reuse and conventional irrigation water on visual turfgrass color at The Creek at Qualchan and Downriver Golf Courses in 2009.

Golf Course	Area	Irrigation Source	Turfgrass color*					
			5/15	6/15	7/15	8/17	9/15	10/15
Qualchan	16 Tee**	Reuse	5	7	8	6	7	7
	16 Tee	Pond	5	7	7	7	6	6
	15 Green***	Reuse	6	7	7	7	7	6
	15 Green***	Pond	6	7	7	7	7	6
	16 Fairway	Reuse	7	8	8	8	8	7
	16 Fairway	Pond	5	7	7	7	7	6
Downriver	6 Tee	Reuse	6	8	7	7	7	6
	6 Tee	City	6	8	7	7	7	6
	7 Rough	Reuse	7	7	8	8	8	7
	7 Rough	City	6	7	5	5	5	4

*Turfgrass color visually rated on a scale of 1 to 9 with 9 = dark green.

**16 Tee irrigated with reuse water constructed June 2008.

***15 Green was reconstructed in fall 2008.

Table 15. The effect of reuse and conventional irrigation water on chlorophyll index readings at The Creek at Qualchan and Downriver Golf Courses in 2009.

Golf Course	Area	Irrigation Source	Chlorophyll index*					
			5/15	6/15	7/15	8/17	9/15	10/15
Qualchan	16 Tee**	Reuse	291	379	462	308	347	353
	16 Tee	Pond	308	344	347	362	311	289
	15 Green***	Reuse	302	389	400	434	365	267
	15 Green***	Pond	303	362	387	445	356	221
	16 Fairway	Reuse	521	459	435	510	554	348
	16 Fairway	Pond	303	398	362	362	326	282
Downriver	6 Tee	Reuse	312	445	339	335	363	314
	6 Tee	City	293	447	326	306	369	294
	7 Rough	Reuse	439	434	480	463	529	334
	7 Rough	City	305	375	284	283	281	171

*Chlorophyll index readings on a scale of 0 to 999 with 999 = very high chlorophyll content.

**16 Tee irrigated with reuse water constructed June 2008.

***15 Green was reconstructed in fall 2008.

Table 16. The effect of reuse and city water, used to irrigate turfgrass, on basic soil test results at Downriver Golf Course averaged each year.

Downriver Golf Course											Interpretation			
		7 Rough				6 Tee				Analysis	Below		Above	
		Reuse water		City water		Reuse water		City water		Method	Optimum	Optimum	Optimum	Unsatis-
Units		2008	2009	2008	2009	2008	2009	2008	2009		Range	Range	Range	factory
pH		6.6	6.8	6.4	6.9	6.9	7.3	6.8	7.1			6.0 - 7.0		< 4.5 & > 8.5
Organic Matter	%	6.0	9.6	6.5	15.8	2.7	1.9	2.2	1.9			1 - 10		> 10
NO ₃ -N	ppm	40	25	28	20	5	6	5	4					
NH ₄ -N	ppm	12		16		5		3						
Phosphorous	ppm	23	18	26	13	73	134	58	156	Bicarb		12 - 15		
Potassium	ppm	277	170	377	151	187	152	161	114	Bicarb		165 - 200		
SO ₄ -S	ppm	23	18	23	14	32	14	27	10			14 - 20		
Boron	ppm	0.6	0.6	0.5	0.5	0.4	0.5	0.3	0.4			0.3 - 0.5		
EC (SS)	mmho/cm	0.57	0.38	0.75	0.36	0.41	0.23	0.31	0.15	Sat. Ext.		< 0.75		> 2.5
Zinc	ppm	7.9	2.7	10.2	2.0	4.7	4.6	4.6	3.2	DPTA		0.8 - 1.5		
Calcium	ppm	57	1843	51	2436	97	1204	100	1122	Sat. Ext.				
Magnesium	ppm	29	353	32	458	19	127	23	92	Sat. Ext.				
Sodium	ppm	23	93	9	53	38	84	12	14	Sat. Ext.				
SAR	meq/L	0.60		0.26		0.81		0.30				< 4.0		> 9.0
CEC	meq/100g	24.0	13.0	48.2	16.6	8.1	7.8	7.2	6.7					

Table 17. The effect of reuse and pond water, used to irrigate turfgrass, on basic soil test results at The Creek at Qualchan Golf Course in 2008 and 2009.

The Creek at Qualchan Golf Course														Interpretation				
	Units	15 Green*				16 Fairway				16 Tee				Analysis Method	Below		Above	
		Reuse water		Pond water		Reuse water		Pond water		Reuse water**		Pond water			Optimum	Optimum	Optimum	Unsatis-
		2008	2009	2008	2009	2008	2009	2008	2009	2008	2009	2008	2009		Range	Range	Range	factory
pH		7.5	7.7	7.4	7.7	6.8	6.8	6.4	6.8	7.5	7.8	6.6	6.9		6.0 - 7.0		< 4.5 & > 8.5	
Organic Matter	%	2.0	0.9	1.7	0.8	2.8	3.0	3.3	4.9	0.4	0.6	3.0	4.5		1 - 10		> 10	
NO ₃ -N	ppm	13	18	6	13	12	12	12	5	2	3	5	4					
NH ₄ -N	ppm	3.2		2.0		5.8		7.9		0.4		7.4						
Phosphorous	ppm	20	11	20	9	11	14	19	24	11	12	21	23	Bicarb	12 - 15			
Potassium	ppm	96	146	81	130	182	128	214	176	38	45	170	128	Bicarb	165 - 200			
SO ₄ -S	ppm	53	13	42	7	13	9	13	11	10	7	17	9		14 - 20			
Boron	ppm	0.2	0.3	0.2	0.2	0.2	0.5	0.1	0.3	0.1	0.3	0.2	0.3		0.3 - 0.5			
EC (SS)	mmho/cm	0.38	0.27	0.29	0.22	0.30	0.24	0.32	0.21	0.13	0.15	0.23	0.19	Sat. Ext.	< 0.75		> 2.5	
Zinc	ppm	1.4	1.4	1.3	0.9	1.9	1.7	1.8	3.8	0.4	0.3	3.6	5.0	DPTA	0.8 - 1.5			
Calcium	ppm	118	1455	140	1448	50	1268	37	1472	36	625	52	1385	Sat. Ext.				
Magnesium	ppm	20	237	21	262	27	324	21	419	12	116	18	296	Sat. Ext.				
Sodium	ppm	21	43	9	19	21	49	9	20	51	65	7	15	Sat. Ext.				
SAR		0.4		0.2		0.5		0.3		1.9		0.2			< 4.0		> 9.0	
CEC	meq/100g	8.2	9.8	9.5	9.8	11.4	9.6	15.1	11.4	30.2	4.5	38.5	9.8					

*Green reconstructed in Fall 2008 with a new sand base and sod from the old green. Soil test reflects the new sand that was used to construct the green.

**Reuse water tee finished construction in June 2008.

Table 18. Initial (15 May 2008) and final (15 Oct. 2009) soil heavy metal levels at the Downriver Golf Course.

Analyte	Soil heavy metal levels (ppm)								MTCA Cleanup Regulations (Ecological Indicator Soil Concentrations for Protection of Terrestrial Plants)*			
	7 Rough				6 Tee				Detect Limit (ppm)	Analysis Method	Prep Method	
	Reuse		City		Reuse		City					
	2008	2009	2008	2009	2008	2009	2008	2009				
Beryllium	0.71	0.55	0.60	0.54	0.47	0.37	0.49	0.37	10	0.02	ICP-MS	3050B Digest
Chromium	21	26	45	23	13	11	14	12	42	0.38	ICP-MS	3050B Digest
Cobalt	6.8	6	5.5	6	4.0	4	4.3	4	20	0.02	ICP-MS	3050B Digest
Nickel	12	13	12	13	8.4	9	8.9	10	30	0.06	ICP-MS	3050B Digest
Copper	14	15	14	15	18	20	16	15	100	0.06	ICP-MS	3050B Digest
Arsenic	6.7	6	7.0	6	12	13	13	12	10	0.38	ICP-MS	3050B Digest
Selenium	< 0.38	<0.38	< 0.38	<0.38	< 0.38	<0.38	< 0.38	<0.38	1	0.38	ICP-MS	3050B Digest
Molybdenum	0.51	1.00	1.0	1.00	0.38	0.49	0.37	0.43	2	0.02	ICP-MS	3050B Digest
Silver	0.63	0.09	0.70	0.11	1.2	0.68	0.96	0.42	2	0.08	ICP-MS	3050B Digest
Cadmium	0.19	0.33	0.59	0.33	0.10	0.15	0.11	0.13	4	0.04	ICP-MS	3050B Digest
Antimony	< 0.38	<0.38	< 0.38	<0.38	< 0.38	<0.38	< 0.38	<0.38	5	0.38	ICP-MS	3050B Digest
Barium	140	130	130	120	88	79	94	73	500	0.04	ICP-MS	3050B Digest
Thallium	0.21	0.18	0.19	0.19	0.15	0.14	0.16	0.13	1	0.06	ICP-MS	3050B Digest
Lead	33	43	41	46	10	12	11	12	50	0.04	ICP-MS	3050B Digest
Mercury	0.074	0.082	0.27	0.340	0.033	0.040	0.042	0.032	0.3	0.008	CVAFS	Nitric/HCl Digest

*Model Toxics Control Act (MTCA) compiled by the Washington State Department of Ecology Toxics Cleanup Program. (WAC 173-340-900). Oct 12, 2007. Page 247.

Website: <http://www.ecy.wa.gov/pubs/9406.pdf>

Exceeds MTCA levels for cleanup.

Table 19. Initial (15 May 2008) and final (15 Oct. 2009) soil heavy metal levels at the Creek at Qualchan Golf Course.

Analyte	Soil heavy metal levels (ppm)												MTCA Cleanup Regulations (Ecological Indicator Soil Concentrations for Protection of Terrestrial Plants)***			
	15 Green				16 Fairway				16 Tee				Detect Limit (ppm)	Analysis Method	Prep Method	
	Reuse*		Pond		Reuse		Pond		Reuse**		Pond					
	2008	2009	2008	2009	2008	2009	2008	2009	2008	2009	2008	2009	(ppm)			
Beryllium	0.28	0.26	0.3	0.25	0.54	0.46	0.59	0.5	0.77	0.39	0.54	0.51	10	0.02	ICP-MS	3050B Digest
Chromium	7.8	7	8.1	7	14	14	15	14	16	10	14	14	42	0.38	ICP-MS	3050B Digest
Cobalt	5.2	5	5	5	6.8	7	6.6	7	4.6	4	6.7	7	20	0.02	ICP-MS	3050B Digest
Nickel	5.6	6	5.6	5	12	12	12	12	10	9	12	12	30	0.06	ICP-MS	3050B Digest
Copper	9	13	8.8	12	11	11	12	12	12	10	11	13	100	0.06	ICP-MS	3050B Digest
Arsenic	1.1	2	1.3	2	7.1	7	7.0	9	14	14	8.9	8	10	0.38	ICP-MS	3050B Digest
Selenium	0.38	<0.38	0.38	<0.38	<0.38	<0.38	<0.38	<0.38	<0.38	<0.38	<0.38	<0.38	1	0.38	ICP-MS	3050B Digest
Molybdenum	0.17	0.26	0.18	0.24	0.31	0.51	0.29	0.49	0.25	0.39	0.26	0.47	2	0.02	ICP-MS	3050B Digest
Silver	0.08	<0.08	0.08	<0.08	0.58	<0.08	0.53	<0.08	0.097	<0.08	0.47	<0.08	2	0.08	ICP-MS	3050B Digest
Cadmium	0.04	0.44	0.044	0.06	0.057	0.10	0.11	0.17	0.086	0.07	0.13	0.27	4	0.04	ICP-MS	3050B Digest
Antimony	0.38	<0.38	0.38	<0.38	<0.38	<0.38	<0.38	<0.38	<0.38	<0.38	<0.38	<0.38	5	0.38	ICP-MS	3050B Digest
Barium	32	33	36	33	100	95	110	100	85	66	97	100	500	0.04	ICP-MS	3050B Digest
Thallium	0.06	0.08	0.06	0.07	0.15	0.15	0.17	0.15	0.16	0.14	0.15	0.17	1	0.06	ICP-MS	3050B Digest
Lead	2.3	3	1.6	4	8.4	10	9.1	11	8.7	9	8.6	11	50	0.04	ICP-MS	3050B Digest
Mercury	0.0	<.012	0.01	<.012	0.0098	<.012	0.013	<.012	0.013	<.012	0.0082	<.012	0.3	0.008	CVAFS	Nitric/HCl Digest

*Green reconstructed Fall 2008 with a new sand base and sod from the old green. Green was resampled for heavy metals on 10/15/08.

**Initial sample taken 6/17/08 after tee was constructed and before effluent water applied.

***Model Toxics Control Act (MTCA) compiled by the Washington State Department of Ecology Toxics Cleanup Program. (WAC 173-340-900). Oct 12, 2007. Page 247.

Website: <http://www.ecy.wa.gov/pubs/9406.pdf>

Exceeds MTCA levels for cleanup.

Table 20. Irrigation suitability of reuse water from the Spokane waste water treatment plant and city water at Downriver Golf Course in 2008 and 2009.

		Irrigation suitability (Downriver GC)						Interpretation		
		Units	Reuse water		City water		Satisfactory	Possible problem	Probable problem	
			2008	2009	2008	2009				
Water Characteristics	pH		7.9	7.7	8.0	7.9	5.5 - 7.5	4.5 - 5.5 & 7.5 - 8.5	< 4.5 & > 8.5	
	Hardness		211	213	212	174	0 - 125	126 - 245	>245	
	Bicarbonate	ppm	85	96	105	168	0 - 111	112 - 525	>525	
	Carbonate	ppm	0.00	0.80	6.00	2.40	0 - 12	13 - 62	>62	
Impact on general growth	EC	mmhos/cm	0.71	0.70	0.27	0.31	0 - 0.75	0.75 - 3.0	>3.0	
	Total Soluble Salts	ppm	451	448	173	198	0 - 480	481 - 1950	>1950	
Impact from root contact	Sodium	meq/l	2.34	2.21	0.34	0.17	0 - 2.9	3.0 - 9.0	>9.0	
	Chloride	ppm	52.7	68.9	4.4	5.8	0 - 140	141 - 360	>360	
	Boron	ppm	0.19	0.10	0.06	0.01	0 - 0.5	0.6 - 2.0	>2.0	
Impact from foliage contact	Sodium	ppm	53.8	50.8	7.8	4.0	0 - 70	71 - 210	>210	
	Chloride	ppm	52.7	68.9	4.4	5.8	0 - 100	101 - 350	>350	
Impact on soil structure	SAR	meq/l	2.63	2.57	0.41	0.25	0 - 6.0	6.1 - 9.0	> 9.0	
	EC	mmhos/cm	0.71	0.70	0.27	0.31	> 0.51	< 0.50		
	Total Soluble Salts	ppm	451	448	173	198				
Plant Nutrients	Nitrate (NO ₃ -N)	ppm	22.80	21.18	7.44	0.80				
	Phosphate (PO ₄)	ppm	0.35	0.47	0.00	0.12				
	Potassium (K)	ppm	9.6	12.1	2.6	3.3				
	Magnesium (Mg)	ppm	24.8	23.9	15.2	17.7				
	Calcium (Ca)	ppm	44.0	45.9	59.6	40.8				
	Sulfate (SO ₄)	ppm	65.7	70.8	15.7	17.4				
	Manganese (Mn)	ppm	0.04	0.01	0.03	0.01				
	Iron (Fe)	ppm	0.01	0.01	0.00	0.01				
	Boron (B)	ppm	0.19	0.15	0.06	0.01				

Table 21. Irrigation suitability of reuse water from the Spokane waste water treatment plant and water pumped from an irrigation pond at The Creek at Qualchan Golf Course in 2008 and 2009.

		Irrigation suitability (Qualchan GC)						Interpretation		
		Units	Reuse water		Pond water		Satisfactory	Possible problem	Probable problem	
			2008*	2009	2008	2009				
Water Characteristics	pH		7.9	7.8	8.2	7.9	5.5 - 7.5	4.5 - 5.5 & 7.5 - 8.5	< 4.5 & > 8.5	
	Hardness		315	214	172	164	0 - 125	126 - 245	>245	
	Bicarbonate	ppm	123	103	127	154	0 - 111	112 - 525	>525	
	Carbonate	ppm	3.60	0.80	7.20	3.20	0 - 12	13 - 62	>62	
Impact on general growth	EC	mmhos/cm	1.47	0.58	0.31	0.29	0 - 0.75	0.75 - 3.0	>3.0	
	Total Soluble Salts	ppm	937.4	369.1	198.4	187.7	0 - 480	481 - 1950	>1950	
Impact from root contact	Sodium	meq/l	8.62	2.26	0.18	0.17	0 - 2.9	3.0 - 9.0	>9.0	
	Chloride	ppm	232.4	71.4	4.8	6.3	0 - 140	141 - 360	>360	
	Boron	ppm	0.22	0.15	0.04	0.01	0 - 0.5	0.6 - 2.0	>2.0	
Impact from foliage contact	Sodium	ppm	198.1	52.0	4.2	4.0	0 - 70	71 - 210	>210	
	Chloride	ppm	232.4	71.4	4.8	6.3	0 - 100	101 - 350	>350	
Impact on soil structure	SAR	meq/l	8.62	2.68	0.25	0.25	0 - 6.0	6.1 - 9.0	> 9.0	
	EC	mmhos/cm	1.47	0.58	0.31	0.29	> 0.51	< 0.50		
	Total Soluble Salts	ppm	938	369	198	188				
Plant Nutrients	Nitrate (NO ₃ -N)	ppm	154.10	21.27	5.47	0.68				
	Phosphate (PQ)	ppm	0.04	0.19	0.00	0.04				
	Potassium (K)	ppm	10.0	13.7	2.1	3.8				
	Magnesium (Mg)	ppm	24.4	24.0	19.1	16.6				
	Calcium (Ca)	ppm	86.0	46.1	37.5	38.4				
	Sulfate (SO ₄)	ppm	65.6	71.5	18.7	16.1				
	Manganese (Mn)	ppm	0.01	0.01	0.02	0.01				
	Iron (Fe)	ppm	0.02	0.02	0.00	0.01				
Boron (B)	ppm	0.22	0.15	0.04	0.01					

*Values excessively high due to sample taken on 10/15/08.

Table 22. The effect of reuse and city water on leaf tissue analysis of turfgrass at Downriver Golf Course in 2008 and 2009.

		Downriver Golf Course								Below	Above	
		7 Rough				6 Tee				Normal	Normal	Normal
		Reuse water		City Water		Reuse water		City Water		Range	Range	Range
Units		2008	2009	2008	2009	2008	2009	2008	2009			
Nitrogen	%	3.96	4.15	3.59	3.16	4.10	4.50	4.02	3.56		3.90 - 4.50	
Phosphorous	%	0.36	0.37	0.33	0.27	0.46	0.45	0.46	0.39		0.29 - 0.50	
Potassium	%	2.62	2.94	2.41	2.45	2.47	2.57	2.39	2.24		2.49 - 3.50	
Magnesium	%	0.28	0.27	0.26	0.26	0.25	0.26	0.24	0.28		0.24 - 0.50	
Calcium	%	0.49	0.45	0.46	0.45	0.42	0.42	0.46	0.47		0.49 - 0.75	
Sodium	%	0.11	0.11	0.04	0.03	0.10	0.10	0.03	0.03		0.01 - 0.16	
Sulfur	%	0.38	0.36	0.36	0.29	0.37	0.34	0.33	0.26		0.25 - 0.40	
Zinc	ppm	37	36	41	32	51	47	44	44		40 - 60	
Manganese	ppm	44	36	56	30	142	107	146	146		41 - 80	
Copper	ppm	9	7	10	6	11	10	10	10		15 - 20	
Iron	ppm	399	320	397	180	1507	1653	1566	2645		125 - 175	
Boron	ppm	11	8	10	6	23	14	15	13		20 - 40	
Molybdenum	ppm	3.81		5.12		4.93		4.38				
Aluminum	ppm	382	248	271	101	996	947	994	1522			

Table 23. The effect of reuse and city water on leaf tissue analysis of turfgrass at The Creek at Qualchan Golf Course in 2008 and 2009.

		The Creek at Qualchan Golf Course												Below		Above
		15 Green*				16 Fairway				16 Tee				Normal	Normal	Normal
		Reuse water		Pond water		Reuse water		Pond water		Reuse water**		Pond water		Range	Range	Range
Units		2008	2009	2008	2009	2008	2009	2008	2009	2008	2009	2008	2009			
Nitrogen	%	4.87	5.24	4.37	4.87	3.87	4.03	3.26	3.32	3.92	3.93	3.83	4.66		3.90 - 4.50	
Phosphorous	%	0.57	0.55	0.53	0.51	0.42	0.40	0.45	0.35	0.47	0.38	0.44	0.44		0.29 - 0.50	
Potassium	%	2.56	2.35	2.29	2.20	2.50	2.80	2.35	2.26	3.00	2.66	2.31	2.37		2.49 - 3.50	
Magnesium	%	0.23	0.26	0.25	0.26	0.30	0.27	0.32	0.26	0.35	0.24	0.29	0.28		0.24 - 0.50	
Calcium	%	0.44	0.47	0.49	0.46	0.42	0.36	0.45	0.40	0.57	0.40	0.48	0.45		0.50 - 0.75	
Sodium	%	0.08	0.06	0.02	0.05	0.07	0.06	0.01	0.03	0.15	0.06	0.02	0.03		0.01 - 0.16	
Sulfur	%	0.44	0.43	0.41	0.39	0.40	0.38	0.36	0.28	0.47	0.34	0.42	0.35		0.26 - 0.40	
Zinc	ppm	53	71	47	65	54	45	40	35	54	40	44	46		40 - 60	
Manganese	ppm	61	72	64	79	51	50	57	76	166	132	134	81		41 - 80	
Copper	ppm	16	16	14	15	10	8	9	7	15	7	12	9		15 - 20	
Iron	ppm	425	1235	932	1510	316	219	278	341	792	435	307	342		125 - 175	
Boron	ppm	13	12	12	11	11	9	8	7	20	15	8	8		20 - 40	
Molybdenum	ppm	3.74		2.76		0.84		4.98		0.01		3.72				
Aluminum	ppm	217	408	516	528	214	165	175	160	516	178	198	155			

*Green reconstructed in Fall 2008 with a new sand base and sod from the old green.

**Reuse water tee finished construction in June 2008.

Table 24. The effect of reuse and conventional irrigation water on visual turfgrass quality at The Creek at Qualchan and Downriver Golf Courses in 2008 and 2009.

Golf Course	Area	Irrigation source	Turf quality*	
			2008	2009
Qualchan	16 Tee**	Reuse	6.5	6.5
	16 Tee	Pond	5.5	6.2
	15 Green***	Reuse	6.5	6.7
	15 Green***	Pond	6.5	6.7
	16 Fairway	Reuse	6.5	7.3
	16 Fairway	Pond	5.8	6.2

Downriver	6 Tee	Reuse	7.0	6.8
	6 Tee	City	7.0	6.8
	7 Rough	Reuse	7.2	7.3
	7 Rough	City	6.5	5.2

*Turfgrass quality rated on a scale of 1 to 9 with 9 = excellent turf quality.

**16 Tee irrigated with reuse water constructed June 2008.

***15 Green was reconstructed in fall 2008.

Table 25. The effect of reuse and conventional irrigation water on visual turfgrass color at The Creek at Qualchan and Downriver Golf Courses in 2008 and 2009.

Golf Course	Area	Irrigation source	Turf color*	
			2008	2009
Qualchan	16 Tee**	Reuse	6.0	6.7
	16 Tee	Pond	6.0	6.3
	15 Green***	Reuse	7.0	6.7
	15 Green***	Pond	7.0	6.7
	16 Fairway	Reuse	7.5	7.7
	16 Fairway	Pond	7.0	6.5

Downriver	6 Tee	Reuse	7.5	6.8
	6 Tee	City	7.5	6.8
	7 Rough	Reuse	7.8	7.5
	7 Rough	City	6.8	5.3

*Turfgrass color visually rated on a scale of 1 to 9 with 9 = dark green.

**16 Tee irrigated with reuse water constructed June 2008.

***15 Green was reconstructed in fall 2008.

Table 26. The effect of reuse and conventional irrigation water on chlorophyll index readings at The Creek at Qualchan and Downriver Golf Courses in 2008 and 2009.

Golf Course	Area	Irrigation source	Chlorophyll*	
			2008	2009
Qualchan	16 Tee**	Reuse	300	357
	16 Tee	Pond	362	327
	15 Green***	Reuse	330	360
	15 Green***	Pond	298	346
	16 Fairway	Reuse	471	471
	16 Fairway	Pond	402	339

Downriver	6 Tee	Reuse	360	351
	6 Tee	City	353	339
	7 Rough	Reuse	463	447
	7 Rough	City	406	283

*Chlorophyll index readings on a scale of 0 to 999 with 999 = very high chlorophyll content.

**16 Tee irrigated with reuse water constructed June 2008.

***15 Green was reconstructed in fall 2008.

Appendix Table 1. Initial (15 May 2008) sand particle size distribution at Downriver Golf Course #6 tee.

Sand particle size distribution - Downriver Golf Course #6 tee (2008)																	
Depth	Reuse water									City water							
		Gravel	Very Coarse	Coarse	Medium	Medium	Med/Fine	Fine	Very fine	Gravel	Very Coarse	Coarse	Medium	Medium	Med/Fine	Fine	Very fine
	USDA (mm)	2.00	1.00	0.50	0.25	0.18	0.15	0.10	0.05	2.00	1.00	0.50	0.25	0.18	0.15	0.10	0.05
	Sieve (mesh)	10	18	35	60	80	100	140	270	10	18	35	60	80	100	140	270
0.25 to 1 in.	%	3.40	3.92	18.72	36.77	15.90	6.12	7.25	5.70	3.25	3.32	16.22	35.22	15.25	5.45	6.00	4.67
1 to 2 in.	%	4.22	3.55	14.12	33.57	15.32	5.32	6.45	4.92	3.27	3.80	15.87	34.80	15.15	5.25	6.27	4.60
2 to 3 in.	%	2.82	2.72	14.32	34.25	16.22	5.50	6.57	5.07	0.80	2.80	17.85	36.40	15.35	5.10	6.10	4.67
3 to 4 in.	%	1.55	2.40	14.72	35.97	16.55	5.60	6.42	4.60	0.65	1.92	14.47	36.92	17.20	5.77	6.60	5.17

Appendix Table 2. Final (15 Oct. 2009) sand particle size distribution at Downriver Golf Course #6 tee.

Sand particle size distribution - Downriver Golf Course #6 tee (2009)																	
Depth	Reuse water									City water							
		Gravel	Very Coarse	Coarse	Medium	Medium	Med/Fine	Fine	Very fine	Gravel	Very Coarse	Coarse	Medium	Medium	Med/Fine	Fine	Very fine
	USDA (mm)	2.00	1.00	0.50	0.25	0.18	0.15	0.10	0.05	2.00	1.00	0.50	0.25	0.18	0.15	0.10	0.05
	Sieve (mesh)	10	18	35	60	80	100	140	270	10	18	35	60	80	100	140	270
0.25 to 1 in.	%	1.50	4.20	21.25	39.50	13.52	5.10	3.77	3.00	0.80	3.72	18.25	38.22	15.12	5.50	4.35	4.10
1 to 2 in.	%	7.40	4.42	19.45	33.02	12.15	4.00	5.12	3.75	1.17	2.52	21.30	36.45	14.55	3.87	5.47	3.95
2 to 3 in.	%	7.10	5.52	16.47	31.57	13.60	5.35	4.27	4.25	1.80	3.45	20.02	35.80	13.97	5.47	4.35	4.17
3 to 4 in.	%	9.30	10.05	17.52	28.17	10.72	3.62	4.30	3.37	1.30	2.25	20.20	37.10	14.25	4.25	5.57	4.07

Appendix Table 3. Initial (15 May 2008) soil particle size distribution at The Creek at Qualchan Golf Course #16 fairway.

Soil particle size distribution - Qualchan Golf Course #16 fairway (2008)																	
Depth	Reuse water									Pond water							
		Gravel	Very Coarse	Coarse	Medium	Medium	Med/Fine	Fine	Very fine	Gravel	Very Coarse	Coarse	Medium	Medium	Med/Fine	Fine	Very fine
	USDA (mm)	2.00	1.00	0.50	0.25	0.18	0.15	0.10	0.05	2.00	1.00	0.50	0.25	0.18	0.15	0.10	0.05
	Sieve (mesh)	10	18	35	60	80	100	140	270	10	18	35	60	80	100	140	270
0.25 to 1 in.	%	0.12	8.12	26.36	27.72	9.56	3.56	5.28	5.56	1.10	9.90	29.60	24.70	9.40	3.80	4.80	4.10
1 to 2 in.	%	9.02	16.85	22.37	20.12	7.20	2.80	4.00	4.47	3.65	11.65	20.75	17.50	8.35	3.60	5.45	6.10
2 to 3 in.	%	13.67	15.82	21.60	19.12	6.90	2.75	3.87	4.45	5.67	6.47	11.05	14.02	9.40	4.40	7.47	10.05
3 to 4 in.	%	9.90	21.40	24.60	18.80	6.80	2.90	3.50	4.10	9.12	9.70	13.07	14.55	8.50	3.95	6.65	9.02

Appendix Table 4. Final (15 Oct. 2009) soil particle size distribution at The Creek at Qualchan Golf Course #16 fairway.

Soil particle size distribution - Qualchan Golf Course #16 fairway (2009)																	
Depth	Reuse water									Pond water							
		Gravel	Very Coarse	Coarse	Medium	Medium	Med/Fine	Fine	Very fine	Gravel	Very Coarse	Coarse	Medium	Medium	Med/Fine	Fine	Very fine
	USDA (mm)	2.00	1.00	0.50	0.25	0.18	0.15	0.10	0.05	2.00	1.00	0.50	0.25	0.18	0.15	0.10	0.05
	Sieve (mesh)	10	18	35	60	80	100	140	270	10	18	35	60	80	100	140	270
0.25 to 1 in.	%	0.32	7.87	25.10	28.37	11.17	4.65	5.42	6.17	0.60	9.00	18.52	21.04	12.92	6.88	6.32	8.32
1 to 2 in.	%	9.75	18.90	19.20	18.92	7.17	3.05	4.60	5.05	1.97	5.42	10.35	15.22	10.62	4.72	8.15	10.10
2 to 3 in.	%	12.65	15.55	19.02	17.82	7.17	3.57	3.70	5.60	5.65	7.85	10.10	13.80	9.30	5.80	6.22	10.30
3 to 4 in.	%	7.32	11.12	16.47	18.25	8.45	3.42	6.17	7.30	1.32	2.12	4.10	13.50	15.77	4.72	11.50	13.10

Appendix Table 5. Initial (15 May 2008) and final (15 Oct. 2009) soil textural analysis at Downriver Golf Course #6 tee.

Textural analysis - Downriver Golf Course #6 tee (2008)								Textural analysis - Downriver Golf Course #6 tee (2009)					
		Reuse water			Pond water			Reuse water			Pond water		
		Sand	Silt	Clay	Sand	Silt	Clay	Sand	Silt	Clay	Sand	Silt	Clay
USDA (mm)		.05 to 2.00	.002 to .05	<.002	.05 to 2.00	.002 to .05	<.002	.05 to 2.00	.002 to .05	<.002	.05 to 2.00	.002 to .05	<.002
Depth	Sieve (mesh)	270 to 18	(Pan)	(Pan)	270 to 18	(Pan)	(Pan)	270 to 18	(Pan)	(Pan)	270 to 18	(Pan)	(Pan)
0.25 to 1	%	94.38	1.36	0.86	86.13	7.21	3.41	90.34	4.08	4.08	89.26	4.97	4.97
1 to 2 in.	%	83.25	8.50	4.03	85.74	7.46	3.53	81.91	4.28	6.41	88.11	6.43	4.29
2 to 3 in.	%	84.65	8.50	4.03	88.27	7.42	3.51	81.03	7.91	3.96	87.23	7.31	3.66
3 to 4 in.	%	86.26	8.27	3.92	88.05	7.67	3.63	77.75	8.09	4.86	87.69	7.34	3.67

Appendix Table 6. Initial (15 May 2008) and final (15 Oct. 2009) soil textural analysis at The Creek at Qualchan Golf Course #16 fairway.

Textural analysis - Qualchan Golf Course #16 Fwy (2008)								Textural analysis - Qualchan Golf Course #16 Fwy (2009)					
		Reuse water			Pond water			Reuse water			Pond water		
		Sand	Silt	Clay	Sand	Silt	Clay	Sand	Silt	Clay	Sand	Silt	Clay
USDA (mm)		.05 to 2.00	.002 to .05	<.002	.05 to 2.00	.002 to .05	<.002	.05 to 2.00	.002 to .05	<.002	.05 to 2.00	.002 to .05	<.002
Depth	Sieve (mesh)	270 to 18	(Pan)	(Pan)	270 to 18	(Pan)	(Pan)	270 to 18	(Pan)	(Pan)	270 to 18	(Pan)	(Pan)
0.25 to 1	%	86.16	9.15	4.57	86.30	8.40	4.20	88.75	6.25	4.68	83.00	11.71	4.69
1 to 2 in.	%	77.81	9.88	3.29	73.40	15.30	7.65	76.89	10.02	3.34	64.58	25.09	8.36
2 to 3 in.	%	74.51	7.88	3.94	62.86	23.08	8.39	72.43	11.19	3.73	63.37	22.13	8.85
3 to 4 in.	%	82.10	5.33	2.67	65.44	16.96	8.48	71.18	16.12	5.38	64.81	22.58	11.29