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# Use of in-stream reservoirs to reduce bacterial contamination of rural watersheds

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## Abstract

An investigation into bacterial water quality problems was conducted on an interconnected stream and irrigation system within the Oldman River Basin of southern Alberta, Canada. Levels of indicator bacteria, including fecal coliforms, generic *Escherichia coli* and fecal streptococci, were repeatedly measured in streams and irrigation return canals of this river basin during the summer of 2001. Bacterial-loading segments of the irrigation/stream system were identified through a comparison of indicator bacteria levels in pairs of upstream and downstream sites. Mann–Whitney *U*-tests indicated that reservoirs significantly reduced bacterial counts. A temporal comparison of *E. coli* counts and river discharges suggested that these indicator bacteria do not originate from within in-stream sediments. Site-specific as well as cumulative inputs from a variety of non-point sources are likely to be responsible for the high downstream levels of indicator bacteria in this water system. The use of management practices such as in-stream reservoirs may significantly reduce contamination, and increase the quality of limited rural water supplies to allow their reuse and safe discharge into downstream water sources. The identification of bacteria-loading river/canal segments could also be used to prioritize restoration projects.

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## 1. Introduction

There is a growing concern about the environmental impacts that agriculture has on surface water

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quality (e.g., Hunter et al., 1999; Bouraoui and Dillaha, 2000; Heathwaite et al., 2000; Crowther et al., 2002; Endreny, 2002; Rodgers et al., 2003). Evidence of this shift in thinking is the ongoing formulation of Environmental Farm Plans (EFP) across Canada (Alberta Environmental Farm Plan, 2002). EFPs provide a voluntary, confidential self-assessment process for agricultural producers to evaluate the environmental risks and strengths of their operations.

Implementing sound land management practices at the farm level has many benefits, including the protection of aquatic systems and human health. Water supplies that become contaminated with manure from livestock, humans and wildlife frequently contain enteric pathogens such as *Cyrptosporidium*, *Giardia* and *Escherichia coli* O157:H7 (Chapman et al., 1994; Van Donkersgoed et al., 1999; Elder et al., 2000; Applebee et al., 2003). Michel et al. (1999) and Valcour et al. (2002) have demonstrated a higher incidence of human verotoxigenic *E. coli* (VTEC) infections in areas with high cattle densities, a principle reservoir for these organisms. Minimizing human exposure to potential pathogen sources, including water supplies used for agriculture, may, therefore, be important for the protection of human health (Valcour et al., 2002).

Recently, outbreaks of waterborne illness, such as in Walkerton, Ontario in 2000 and North Battleford, Saskatchewan in 2001, have raised public concern regarding the quality of water in agricultural regions with high livestock densities, such as the Oldman River watershed in southern Alberta, Canada (Gannon et al., 2002). In 1997, a cooperative program began between Health Canada, Alberta Agriculture, the Chinook Health Region (CHR), the Lethbridge Northern Irrigation District (LNID), Alberta Environment, the Oldman River Basin Water Quality Initiative (ORBWQI), the City of Lethbridge and the University of Lethbridge. As a result of this collaborative effort, it has been demonstrated that water samples from 120 locations within the Oldman River watershed frequently have high levels of bacterial indicator species (i.e., fecal coliforms) and bacterial pathogens (i.e., *E. coli* O157:H7, *Salmonella* spp. and *Streptococcus* spp.) (Gannon et al., 2002; Hyland et al., 2003; Johnson et al., 2003; Little et al., 2003).

Based on the high bacterial counts in cattle feces (Chapman et al., 1994; Van Donkersgoed et al., 1999; Elder et al., 2000; Applebee et al., 2003), and the high concentration of cattle and confined livestock operations in the study area (Alberta Agriculture Food and Rural Development, 2001), there is concern that confined livestock operations may be contaminating surface waters in the Oldman River Basin. However, the studies carried out to date have not found a statistically significant relationship between bacterial water quality and confined livestock operations (Johnson et al., 2003; Little et al., 2003). The unique spatial characteristics between upstream and downstream sites (e.g., Little et al., 2003), and the rise in bacterial contamination following precipitation events (Hyland et al., 2003; Little et al., 2003), suggest that the bacterial contamination may be the result of a number of factors other than animal density. These factors are likely to include the runoff topology of the landscape and farm-specific practices, such as grazing practices, access of livestock to streams, and the timing and amount of manure applied to fields as fertilizer.

In contrast to previous research conducted in this region that investigated large-scale statistical relationships (or trends) (Hyland et al., 2003; Johnson et al., 2003; Little et al., 2003), the objective of this study was to identify specific bacteria-loading areas in the study region. Stream and irrigation canal segments were identified along which bacterial contamination of water increased significantly and other segments where it decreased. This approach could be a valuable method to prioritize restoration projects, such as Alberta's EFP initiative.

## 2. Materials and methods

### 2.1. Study area

The study area is located in the Oldman River watershed in Alberta, Canada, between 51°0′ and 49°27′N latitude and 112°18′ and 114°6′W longitude (Fig. 1). The region is a typical semi-arid continental climate in the rain shadow of the Rocky Mountains. Warm dry summers and winters with extreme temperatures and precipitation variability occur due to warm dry Chinook winds associated with dominant westerly

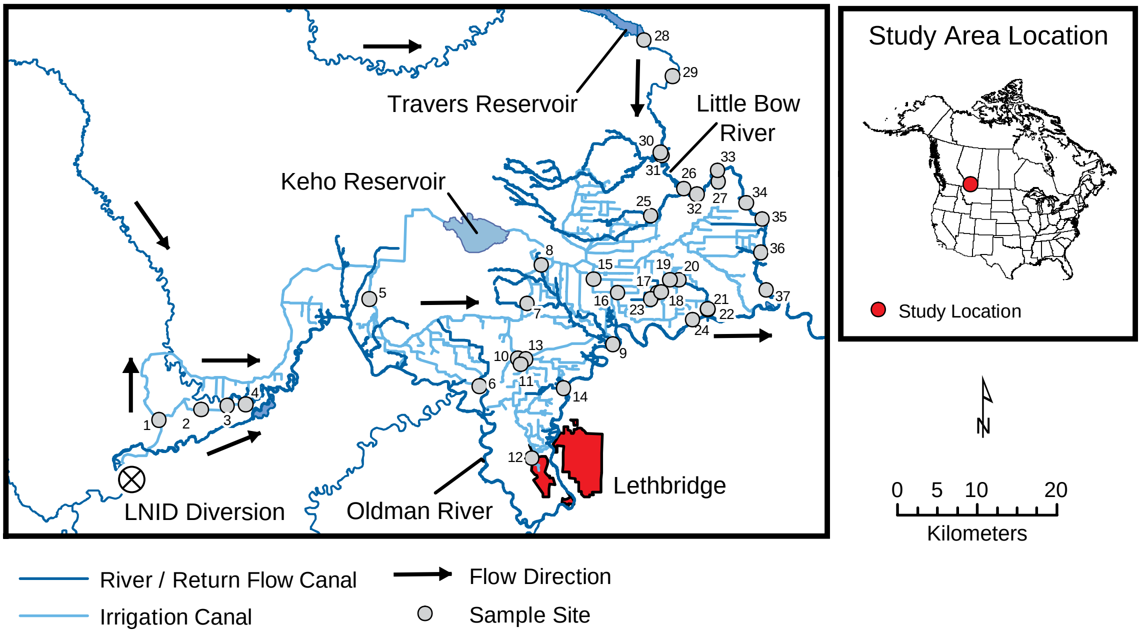

Fig. 1. Study area.

air flows. July and January average temperatures are 18.5 and −8.5 °C and average annual precipitation is 264.6 mm for Lethbridge, Alberta (Fig. 1) (Environment Canada, 2002). On average, 70% of annual stream flow volume occurs in 3 months (May, June and July) originating as snowmelt in the Rocky Mountains to the west. Mollisol (Chernozemic) soils dominate the region and typically have high infiltration rates for grassland cover that easily absorb normal summer rainfall. Local runoff is retained in numerous small potholes and wetlands scattered over the region. Overland flow may, however, reach surface water bodies along riparian areas and near rural infrastructure (Heathwaite et al., 2000; Duke et al., 2003). Most irrigation infrastructure in the LNID is open channel canals. Return flows are discharged into either the Oldman River or the Little Bow River. Excess supply water is also drained into the return flow canals from surface and subsurface runoff, tile drainage and groundwater.

The LNID provides irrigation water from the Oldman River to over 50,000 ha through a network of irrigation canals and three off stream storage facilities: Keho, Picture Butte and Park Lake Reservoirs. Irrigation agriculture and confined feeding operations dominate the study region. There are about 1.1 million cattle in the region, twice the number of any other census division in the province (Alberta Agriculture Food and Rural Development, 2001). Cow-calf operations and dryland agriculture are also present in the study area, but comprise a much smaller proportion of the land base. In 2001, the irrigated crop mix in the LNID was 48% barley, 15% alfalfa, 7% corn, 6% hay, 6% wheat, 3% canola, 3% tame pasture and 2% native pasture. Other varieties comprised about 10% of the crop mixture (Gary Burke, LNID, personal communication, November 10, 2004).

Nutrient sources in the region include livestock operations, farm runoff, effluent treatment plants and an unknown wildlife contribution. Eight small towns and villages are in the study region—none of them discharge effluents into the irrigation LNID return flow canals during the irrigation season. In 2001, Shaughnessy (the only town licensed to discharge treated effluent into a return flow canal) disposed of approximately 13,500 $m^3$ of municipal effluent in the late fall (well after our sampling period) through the lowest few kilometers of the Piyami drain (site 9) to the Oldman River (Ben Lichtenwald, Alberta Environment, personal communication, November 19, 2004).

### 2.2. Water sample collection and analysis

Grab samples were collected from 37 monitoring sites within open channel irrigation canals and stream channels (Hyland et al., 2003) at least every 2 weeks from May 5th to September 25th, 2001 (Fig. 1). Water samples (1 l) were chilled on ice after collection and counts of *Streptococcus*, *E. coli* and fecal coliforms were measured. *E. coli* and fecal coliforms were enumerated by a membrane filtration technique at the Provincial Laboratory of Public Health, Foothills Hospital, Calgary, Alberta. Counts represent the total number of bacteria as colony-forming units (cfu) per 100 ml.

The method used for enumeration of enterococci (*Streptococcus*) was modified from the United States Environmental Protection Agency Method 1600 (USEPA, 2002). Following agitation, two separate 50 ml and 100 ml volumes were passed through separate 0.45 μm membrane filters (Pall, Mississauga, Ontario). Filters were placed onto trypicase soy agar (TSA, Oxoid, Nepean, Ontario) and incubated for 4 to 6 h at 37 °C. Filters were then aseptically transferred from the TSA plates to modified *Enterococcus* agar (mEA, Oxoid, Ontario) and incubated at 42 °C for 48 h. Next the filters were transferred to Esculin Iron Agar (EIA, Dalynn, Calgary, Alberta) and incubated at 42 °C for 20 min. Pink to reddish colonies that developed a black to reddish-brown precipitate in the agar beneath the filter were counted. For confirmation of *Enterococcus* species, five of the colonies isolated from each water sample were tested for growth in Brain Heart Infusion Broth (BHI, Oxoid) containing 6.5% NaCl at 45 °C, and for catalase production (Difco, Sparks, MD, USA) and hemolysis on 5% sheep blood agar after incubation for 24 h at 37 °C.

The number of samples collected and analyzed per site ranged from 12 to 24 for *E. coli* and fecal coliforms, and from 9 to 14 for *Streptococcus*. The range in sample numbers was due to a variety of reasons: (1) the availability of study personnel to conduct the sampling; (2) the occurrence of bacterial cultures with a density that was too numerous to count on the membrane filter; and (3) the delay in analysis of *Streptococcus* until June 20th, 2001.

In addition to bi-weekly collection, samples were also collected at the sites along the Little Bow River during precipitation events. The additional samples were collected because natural drainage systems may be more vulnerable to overland flow, in contrast to irrigation canals that are often flanked by berms and are frequently located along highpoints in the landscape where saturated overland flow is less likely to occur (Heathwaite et al., 2000). Only five samples were taken and analyzed for *E. coli* at sites 9 and 24 due to infield access and logistical difficulties, and only a single sample of these 5 samples was analyzed for *Streptococcus* due to the delayed commencement in testing for this bacterium.

### 2.3. Precipitation and discharge data

Precipitation data were obtained for Lethbridge, Alberta from the Canadian Daily Climate database (Environment Canada, 2002). Discharge data were also obtained for the gauging station at the mouth of the Little Bow River and below Travers Dam (Fig. 1) from Environment Canada's HYDAT database (Environment Canada, 2001).

### 2.4. Data analysis

To get an impression of the central tendency and variation of the data, descriptive statistics by site, including box and whisker plots, were calculated for the counts of each of the bacteria. Pearson's correlation coefficients were calculated to determine correlations between bacterial results among the samples, and between bacterial results and water discharge volumes at specific sites of interest.

Mann–Whitney *U*-tests were conducted to determine whether there was a significant difference ($P<0.05$) in *E. coli* counts between sampling locations due to the non-normally distributed count data. The Mann–Whitney *U*-test is a non-parametric two-sample rank test that measures the equality of two population medians. The stream and canal segments that showed significantly increased or decreased bacterial pollution along the segment were mapped to facilitate visualization of significant bacterial-loading and unloading stream/canal segments.

## 3. Results

The *E. coli* and *Streptococcus* counts for the 37 sampling locations are summarized with box and

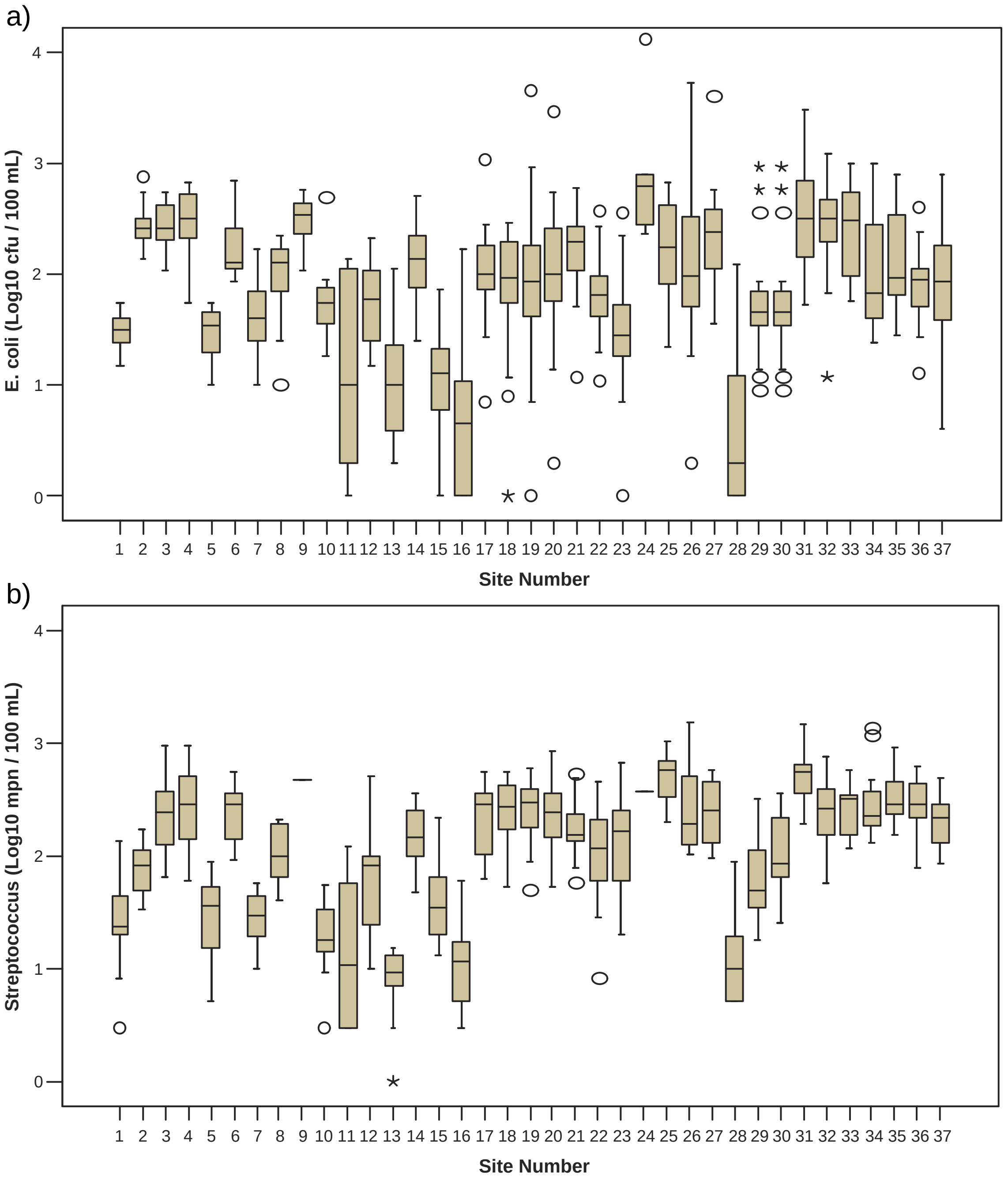

Fig. 2. Box and whisker plots of central tendency and variability for (a) *E. coli* counts and (b) *Streptococcus* counts of Oldman River water samples, by site, taken during the summer of 2001. Outliers (shown with circles) are cases with values between 1.5 and 3 box lengths from the upper or lower edge of the inter-quartile range. Extremes (shown with stars) are cases with values more than 3 box lengths from the upper or lower edge of the inter-quartile range.

whisker plots in Fig. 2. *E. coli* counts ranged from 0 to 5200 cfu/100 ml. *Streptococcus* counts ranged from 0 to 1540 cfu/100 ml. Both *E. coli* and *Streptococcus* data were also $\log_{10}$ transformed for the analysis (Fig. 2). The Pearson's correlation coefficient for fecal coliform and *E. coli* counts was 0.950 ($P<0.01$) (data not shown).

The 25th and 75th percentiles of sample sites 11, 13, 15, 16 and 28 are lower than, and do not overlap, the majority of the inter-quartile ranges of the other sampling sites (Fig. 2a). Site 16 is immediately downstream of the Picture Butte Reservoir; site 28 is immediately downstream of the Travers Reservoir; sites 13 (and 11) are immediately downstream of the Park Lake Reservoir; and site 15 is one of several sampling sites located downstream of the Keho Reservoir. The box plot of *Streptococcus* counts (Fig. 2b) followed the same pattern for these five sites with the exception of site 15 that had somewhat higher counts.

Fig. 3 shows the river/canal segments that were significantly different in *E. coli* counts between sampling sites based on the Mann–Whitney *U*-statistic. In the western extent of the LNID (Figs. 2 and 3, sites 1–14), the lowest levels of *E. coli* occurred in two irrigation outflow canals immediately following the Park Lake Reservoir (sites 11 and 13). Sites 1, 5 and 7, located within the canal mainline, had slightly higher *E. coli* counts. Based on the *U*-statistics, a significant increase in levels of fecal coliforms was observed between sites 1 and 2, between sites 5 and 6, between sites 7, 8 and 9, and between sites 11, 13 and 14 (Figs. 2 and 3).

The Battersea Drain canal system (Figs. 2 and 3, sites 15–22) showed similar changes in *E. coli* counts as the western extent of the LNID. Although the *E. coli* counts were relatively low at site 1, the water quality improved across Keho Reservoir (segments 1–15) and yet again across the Picture Butte Reservoir (segments 15–16). In the canal segment immediately downstream of the Picture Butte Reservoir, *E. coli* counts increased significantly, after which no significant changes were found (segments 17–22) (Figs. 2 and 3).

Levels of *E. coli* also increased significantly at downstream sites on the Little Bow River (Figs. 2 and 3, sites 28–37). The box plot in Fig. 2 shows two significant increases in *E. coli* counts. The first segment is located between sites 28 (below Travers Dam) and 29, which is upstream of all of the irrigation

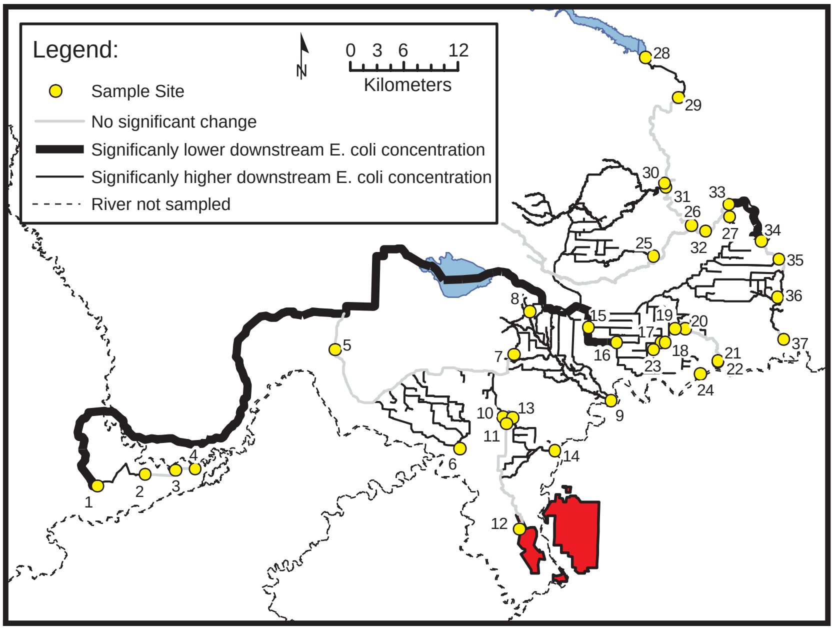

Fig. 3. Differences in *E. coli* loading of river/canal segments along the Little Bow River and LNID in 2001, determined with the Mann–Whitney *U*-test ($P\leq0.05$).

return flow canals in this area. The second segment is located between sites 30 and 31 and receives irrigation return flows that drain the area to the west of site 31 (Fig. 3). The Mann–Whitney *U*-test confirmed the observed significance from this box plot analysis for each of these river segments. Although the interquartile ranges of sites 33 and 34 (located downstream) overlap (Fig. 2), the median *E. coli* count was significantly reduced (according to the Mann–Whitney *U*-statistic). This stretch of river is the only segment along which a downstream site had significantly lower *E. coli* counts and yet did not contain a reservoir. Because site 1 was the only upstream sampling location from sites 35, 36 and 37 (within the LNID distribution system), many of the LNID return flow canals near the terminus of the Little Bow River showed significantly higher downstream *E. coli* counts.

## 4. Discussion

Out of four river/canal segments that showed significantly lower downstream *E. coli* counts, three contained a reservoir (Keho Reservoir located between site 1 and site 15, Picture Butte Reservoir located between site 15 and site 16, and Park Lake Reservoir located between site 10 and 13 [not shown due to map scale]). The significantly lower *E. coli* counts downstream of reservoirs suggest that the low flow velocities and residence times within the reservoirs of southern Alberta are a significant cause of fecal coliform, *E. coli* and *Streptococcus* sedimentation and/or bacterial die off. Gannon et al. (1983) and Auer and Niehuas (1993) found that, with a settling rate of 1.5 m/day, approximately 90% of fecal coliforms were removed. It is also known that planktonic forms of enteric bacteria such as *E. coli* die off rapidly in raw water (Wang and Doyle, 1998).

The results of this study indicate reservoirs remove microbial pollutants in agricultural wastewaters. Constructed wetlands near the terminus of return flow canals, storm sewer outlets in urban areas and in industrial effluents channels will likely provide an effective means to remove biological pollutants before they reach important drinking water sources. Constructed wetlands also reduce suspended particulates, organic compounds and metals in water through a variety of biological, chemical and physical mechanisms (Gearheart, 1999; Shutes, 2001; Goulet et al., 2001; Runes et al., 2003). The use of a constructed wetlands or reservoirs to improve the quality of wastewater is restricted by the need for relatively impermeable soils, and a basin with adequate storage capability to permit efficient sediment trapping. Reservoir design should ensure that adequate settling occurs and that sediment resuspension from wave turbulence is minimized.

While good for water quality in the river downstream, the sedimentation of bacteria in local reservoirs may pose a potential human health risk. Several studies have reported that bacterial concentrations can be up to 1000 times greater in sediment than in the overlying water column (Hendricks and Morrison, 1967; Van Donsel and Geldreich, 1971; Stephenson and Rychert, 1982; Karim et al., 2004). In another study, Karim et al. (2004) reported an average reduction in fecal coliform counts after 14 days in water of 6026 cfu/100 ml, in contrast to a die off rate of only 141 cfu/100 g of sediment in a constructed wetland. The prolonged survival of bacteria in sediments suggests an increased risk of exposure to potentially pathogenic microorganisms may result from sediment resuspension (Craig et al., 2002; Alm et al., 2003).

Even though *E. coli* counts in the Park Lake Reservoir were low, these waters may present a risk of human infection from waterborne bacteria simply because of the high level of recreational use of a beach established on this reservoir. There are a number of reasons for this public health concern: (1) the number and size of confined cattle feeding operations in the study area is the highest in Alberta (Alberta Agriculture Food and Rural Development, 2001); (2) Van Donkersgoed et al. (1999) reported a high prevalence of zoonotic pathogens such as verotoxigenic *E. coli* O157:H7 in cattle feces in southern Alberta; (3) studies in southern Ontario have established a strong correlation between human verotoxigenic *E. coli* infection rates and cattle densities (Michel et al., 1999; Valcour et al., 2002); (4) several drinking water and recreational water outbreaks of waterborne disease have been reported that have involved zoonotic pathogens from cattle such as *E. coli* O157:H7 (Samadpour et al., 2002; Hrudey et al., 2003); and (5) high levels of indicator bacteria and bacterial pathogens such as *E. coli* O157:H7 and *Salmonella* have been isolated from surface waters in the study area (Gannon et al., 2002; Hyland et al., 2003; Johnson et al., 2003; Little et al., 2003). The risk of exposure at the Park Lake beach is, in all likelihood, exacerbated given the fact that fecal coliform and *E. coli* counts have been reported to peak in surface water during the warmest months of the year, July and August (Hyland et al., 2003; Johnson et al., 2003), when the beaches are the busiest in this region.

Two previous studies have reported that they were unable to predict bacterial water quality based solely on land use patterns in this region (Johnson et al., 2003; Little et al., 2003). In the water systems measured in this study, differences in concentrations of indicator bacteria in flowing water generally increased from upstream to downstream. This was likely due to the accumulated contributions from numerous point and non-point sources as the water flows downstream. Within the LNID, land use and animal density is spatially distributed in a random fashion. Therefore, land use and animal density would only be expected to be correlated with levels of indicator bacteria if upstream "historical" fecal inputs were constantly being removed because the storage and transfer of bacteria from the land to stream channels is both temporally and spatially dynamic. In addition, it is evident that significant quantitative differences in the contributions to fecal contamination of these surface waters is likely to be a result of specific differences in topography, infrastructure design and land management practices, rather than strictly proportional to average land use and animal density. Indeed, it is possible that most land managers are adequately ensuring local surface waters do not receive point-source or non-point-source bacterial contaminants under most circumstances and under average weather conditions. The identification of significant *E. coli*-loading stream/canal segments in this study, however, indicates that either some farm practices may be disproportionately contributing to the bacterial contamination of local surface waters, or resuspension of bacteria laden sediment is occurring between sites.

Figs. 4 and 5 show the *E. coli* and *Streptococcus* counts reported at sites 30 and 31, respectively. Site 31 was the most highly contaminated site in the region. A substantial rise in *E. coli* counts during the first precipitation event of the summer (June 3rd, 4th and 5th) was measured at both sites (Fig. 6a). At the same time, discharge in the Little Bow River increased substantially below Travers Dam (Fig. 6b). Because site 30 is upstream of all irrigation return flow canals, the discharge in Fig. 6b was assumed to be representative of the flow volumes at site 30.

The rise in bacterial water counts at the onset of a precipitation event, following a period of dry weather, has been referred to as the "first flush" phenomenon (Tong and Chen, 2002). During the first flush, land stores of bacteria and other pollutants, are depleted within the runoff contributing area of the watershed as runoff moves into water courses (Jenkins et al., 1984; Tong and Chen, 2002). Rises in bacterial water counts can also be the result of resuspension of microbes from in-channel storage (viz. sediments) (McDonald

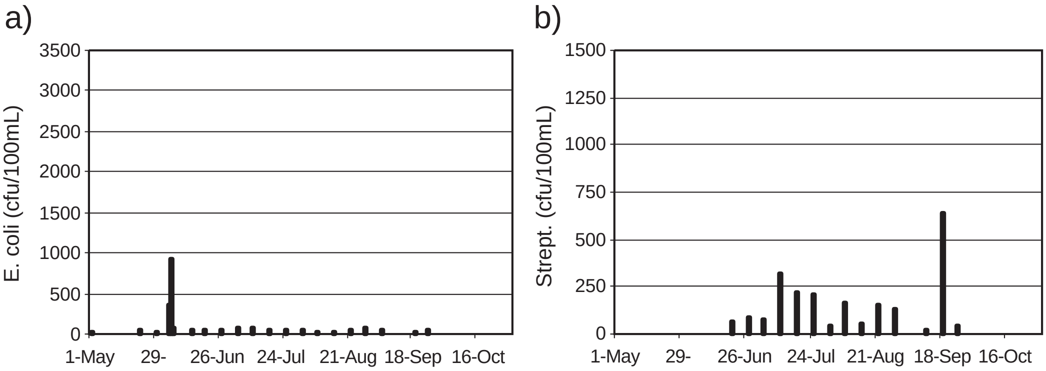

Fig. 4. (a) *E. coli* count and (b) *Streptococcus* count at site 30 along the Little Bow River in 2001. *Streptococcus* was not measured until June 20th.

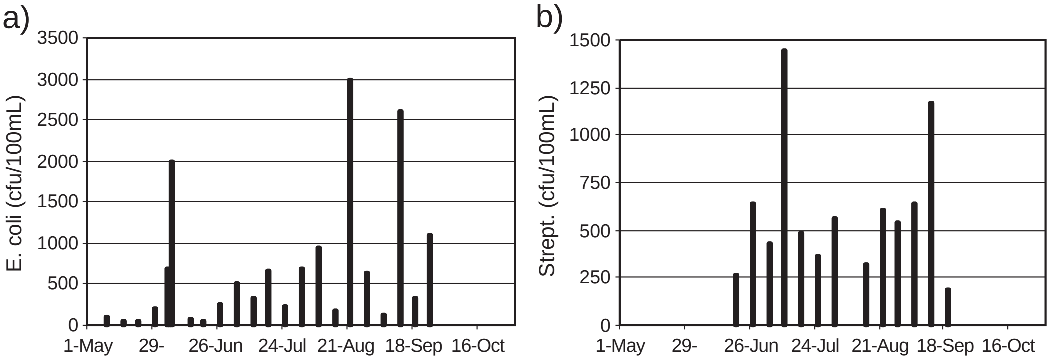

Fig. 5. (a) *E. coli* count and (b) *Streptococcus* count at site 31 along the Little Bow River in 2001. *Streptococcus* was not measured until June 20th.

and Kay, 1981; McDonald et al., 1982; Wilkinson et al., 1994; Miurhead et al., 2004). To determine which of these mechanisms (in-stream sediments or land use activities) may be responsible for the observed peaks in *E. coli* counts at sites 30 and 31 in early June 2001, we examined the *E. coli* counts and water discharge recorded near the mouth of the Little Bow River at site 37 (Fig. 7). This site was selected because it was the only site downstream of Travers Dam at which both discharge and water quality data were available. Inspection of Fig. 7 indicates that similar peaks in *E. coli* count were not reported during episodes of increased discharge later in the summer. The relatively weak correlation between discharge and *E. coli* counts (Pearson's correlation of 0.594) suggests that the peaks in *E. coli* at sites 30 and 31 did not originate solely within in-stream sediments.

The land upstream of site 30 is used primarily as pasture for grazing cattle (Fig. 8). An irrigation return flow canal that flows adjacent to a small feedlot operation enters the Little Bow River upstream of site 31. Field observations at site 31 confirmed that livestock have direct access to the stream between sites 30 and 31. Based on these observations, it is possible that the feedlot, grazing cattle, or another source in the sub-watershed of site 31 could contribute to bacterial contamination of the stream. Conducted at the field scale, an EFP (or another assessment practice) would identify the land use operations and/or drainage topology structure (i.e., field-to-stream linkages) that may be leading to the degradation in water quality. Confining runoff from drainages and irrigation return flow channels, before they discharge into local streams, could be an effective mechanism to minimize bacterial loads entering surface water systems (Karim et al., 2004).

Even though the precise source and host-species origin of the contaminants are unknown, identification

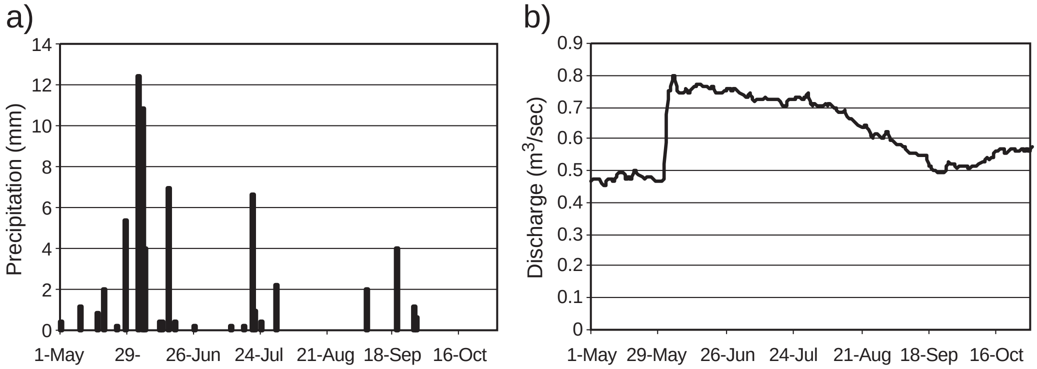

Fig. 6. (a) Precipitation measured in Lethbridge and (b) Little Bow River water discharge measured below Travers Dam in 2001.

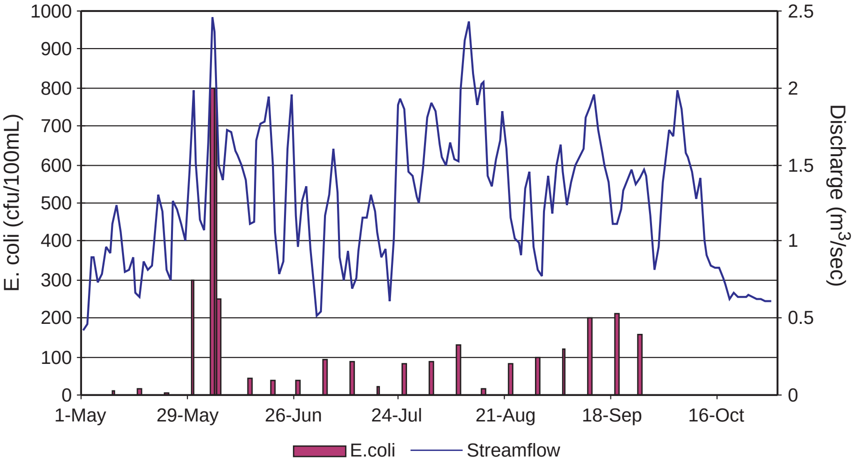

Fig. 7. *E. coli* and discharge recorded near the mouth of the Little Bow River (site 37).

of these bacteria-loading segments could be used as means to proactively prioritize restoration projects and to aid in the decision making process by regulatory agencies. Stream/canal segments along which significant increases in contamination occur should receive the highest priority for new land management strategies. The increased downstream *E. coli*, *Streptococcus* and fecal coliform counts throughout the LNID suggest that open channel irrigation canals promote field-to-stream linkages by increasing the drainage density of the landscape. Because soils in irrigated landscapes are maintained at higher soil moisture levels, the likelihood of rainfall events producing runoff may also be increased. The combination of irrigation and the existence of rural infrastructure elements (canals, culverts and roads) may,

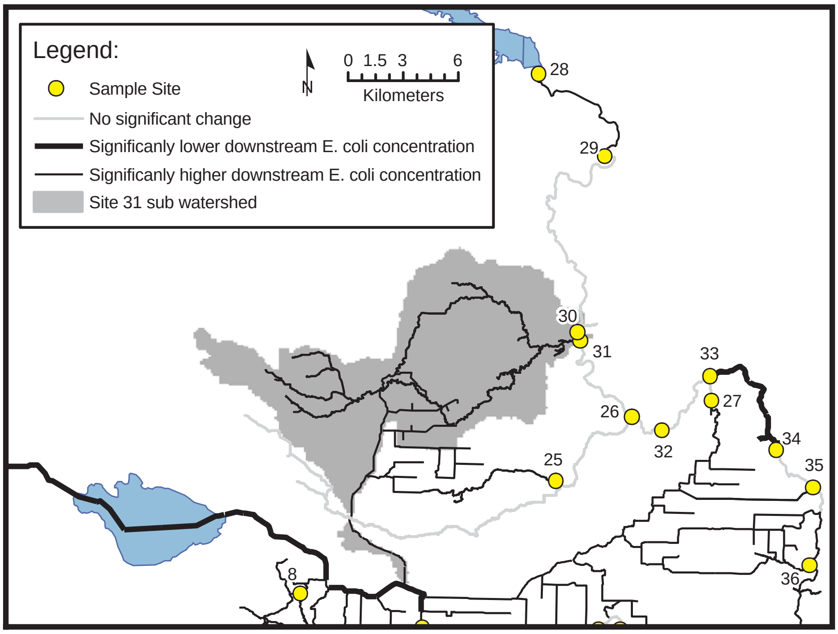

Fig. 8. Sub-watershed map for site 31 delineated from a 20-m DEM taking into account rural infrastructure (roads and irrigation canals) with RIDEM (Duke et al., 2003).

therefore, be increasing the vulnerability of surface waters to pollution in the region. These types of linkages have been shown to affect the timing, magnitude and quality of stream flow in other landscapes (Dybvig and Hart, 1977; Montgomery, 1994; Wemple et al., 1996; Dijck, 2000; Jones et al., 1999; La Marche and Lettenmaier, 2001; Nyssen et al., 2002). Mitigative measures, such as vegetative buffers (Coyne et al., 1998; Endreny, 2002), livestock distribution management (Tiedmann et al., 1987, 1988), runoff impoundment (Pontier et al., 2004) or in-stream mechanisms such as settling ponds (Karim et al., 2004), should be implemented along the bacterial-loading stream/canal segments for the protection of aquatic systems and human health.

## 5. Conclusions

This study indicates that two-sample rank Mann–Whitney *U*-tests can be used to identify segments of streams and irrigation canals with significant differences in indicator bacteria. Using this approach, we were able to identify river/canal segments that appeared to disproportionately contribute to bacterial contamination of surface waters in southern Alberta. These stream segments are good candidates for implementation of best management practices to improve water quality. Our results also show that reservoirs in southern Alberta had significantly lower levels of fecal indicator bacteria than flowing waters. This may be the result of slower flow rates and faster sedimentation rates of bacteria associated with particulates in reservoirs. We caution that use of reservoirs supplied by water from irrigation distribution systems draining agricultural areas for recreational swimming may present a risk to human health associated with waterborne zoonotic pathogens. However, the results indicate that in-stream use of reservoirs may reduce bacterial contamination and increase quality of water sources downstream of agricultural activities.

## Acknowledgements

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