A REVIEW OF
THE ENCLOSURE OF WATERCOURSES IN
AGRICULTURAL LANDSCAPES AND
RIVER HEADWATER FUNCTIONS

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Submitted to: Fisheries and Oceans Canada

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EXECUTIVE SUMMARY

The enclosure of surface watercourses in agricultural landscapes is occurring in Ontario. The purpose of this literature review was to identify the potential environmental benefits and impacts of enclosing open, surface drains, or watercourses, as a first step in evaluating this practice in agricultural landscapes. If information about this practice was not available (as suspected by the advisory committee), then the review was to identify the deficiencies in the literature related to this topic and provide a general introduction to headwater function and potential impacts of agricultural drainage to these systems.

A thorough search of the literature indicated there were several deficiencies in the literature related to the identification of the potential benefits and impacts of enclosing open, surface drains, or watercourses, in agricultural landscapes. Significant highlights of the findings are listed below:

1. No references identified an interest or concern about the effects of enclosing open drains in agricultural landscapes.
2. It followed that no references focused on the potential benefits and impacts of enclosing open, surface drains, or watercourses in agricultural landscapes.
3. No references specifically identified open drains in agricultural landscapes as headwaters.
4. Several references identified best management practices (BMP) to mitigate the environmental impacts of adjacent agricultural land use and of open drains. These references indicated that BMPs affect many of the same processes/functions that are identified in the body of literature related to river headwater functions, although none of the former references used the specific term ‘headwater functions’.
5. No references compared the characteristics or functions of open drains vs. natural streams although many references compared the headwater functions of natural, agricultural, managed forest and/or urban watersheds. Few of this latter group of references identified or discussed the substructure of the agricultural drainage system i.e. surface and subsurface drainage components, presence of open and
enclosed drains, and where the open drains stopped/started and the ‘natural’
watercourses began.
6. Many references discussed the impact of agricultural land use on water quality and
quantity.
7. There was no recognition in the literature of open agricultural drains as a location
for comparative research.
8. Many references compared the environmental impacts of land uses adjacent to
watercourses including forested, urbanized and agricultural uses.

Natural landscapes (generally unmanaged forest) represent the standard against which
comparisons of headwater functions in other landscapes, including agriculture, often are
made. Headwaters include the lowest order streams i.e. zero-, first-, and second-order
streams. They may constitute at least half of the river’s total length and may join the river
continuum at any point along its path. Headwaters perform three functions that are
broadly categorized as hydrologic, physico-chemical and habitat/food web. It was
concluded from this review that the findings from studies in natural landscapes may, or
may not, be directly applicable to agricultural landscapes since agricultural landscapes
are highly disturbed by human activity. Agricultural landscapes are and will continue to
be an essential component of food production. Therefore, it was concluded that
agricultural landscapes represent a standard land use within which comparisons of the
headwater functions in natural watercourses, open drains and enclosed drains should be
made.

The advisory committee agreed that to evaluate the potential benefits and impacts of
enclosing open, surface drains, or watercourses, in agricultural landscapes the following
questions should be addressed through further research:
1. a) Do open drains perform headwater functions and, if so, how well?
   b) How do headwater functions compare between natural streams and channelized
      watercourses in agricultural landscapes?
2. Do enclosed drains perform headwater functions and, if so, how well?
3. How do woodlots and best management practices (BMPs) affect headwater functions in natural watercourses, open drains and enclosed drains?

4. Does enclosure affect the health of the local and downstream environments?

5. a) What are the impacts of the surrounding land use on headwater functions?

   b) What are the impacts of enclosing drains compared to the impacts of the surrounding land use on headwater functions?

It is important to recognize that whatever practices are necessary to produce food, they must ensure that agricultural sustainability is achieved by meeting environmental, economical and societal needs.
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1 INTRODUCTION

Drainage systems that remove excess water from agricultural landscapes are generally developed in two stages (Skaggs et al., 1994). The first stage occurs when land use changes from native vegetation to agricultural crop production. In North America, much of the first stage of development has already occurred (Skaggs et al., 1994). The second stage of drainage development involves improving the existing drainage system to increase or sustain crop yields and the efficiency of production (Skaggs et al., 1994). In Ontario, excess water has been drained from land to improve agricultural production for over 150 years (Fraser and Fleming, 2001).

Open drainage ditches link surface and subsurface drainage systems in agricultural fields with streams or rivers that represent an ‘adequate outlet’ for the gathered water (Irwin, 1997). Existing open drains, however, are sometimes enclosed in large tile or conduits and buried underground. This enclosure may facilitate equipment movement or operational safety in agricultural fields. It also may provide the producer with greater flexibility in meeting fertilizer and pesticide application specifications, or minimum distance separation regulations for new facilities. The following excerpt from the Fish Habitat Plan of the Ausable Bayfield Conservation Authority (ABCA) (Veliz, 2001) first identified the enclosure of open drains as an agricultural practice that may be increasing in use in Ontario.

The transformation from open, surface drains to closed, tiled drains is occurring in the ABCA jurisdiction. However, the extent to which this activity has occurred is unknown. Therefore, drain closures between 1975 and 1999 were examined in one sub-basin, the Nairn Creek sub-basin. The total length of open watercourses in 1975 was determined from the 1975 enlargements (1:5 000) of aerial photographs (1:20 000). The length of closed, tiled drains in 1999 was determined from the 1999 (1: 15 000) aerial photographs. (The length of the watercourse that no longer appeared was assumed to be the amount of the watercourses that was
closed and tiled.) The amount of watercourse closed and tiled in 1999 is expressed as a per cent of the total length of open, surface drains (1975). The findings from this preliminary survey suggested that 14 % of open watercourses in this sub-basin had been transformed to closed, tiled drains. (Veliz, 2001)

At the outset of this review, little information had been collected to determine the direct and indirect benefits and impacts of this practice in agricultural landscapes. The primary purpose of this review was to identify the potential environmental benefits and impacts of enclosing open, surface drains, or watercourses. If literature on this practice was not available (as suspected by the advisory committee), then the review was to identify the deficiencies in the literature related to this topic and, with the remaining resources, provide a general introduction to headwater function and potential impacts of agricultural drainage to these systems.

2 METHODS

2.1 TERMS OF REFERENCE

Terms of reference were provided (Appendix 1) as an initial guide for this work. Further direction was provided by the advisory committee (Appendix 2), which included:

<table>
<thead>
<tr>
<th>Name</th>
<th>Organization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tom Prout</td>
<td>Ausable Bayfield Conservation Authority (ABCA)</td>
</tr>
<tr>
<td>Mari Veliz</td>
<td>Ausable Bayfield Conservation Authority (ABCA)</td>
</tr>
<tr>
<td>Jane Sadler Richards</td>
<td>Cordner Science</td>
</tr>
<tr>
<td>Norm Smith</td>
<td>Department of Fisheries and Oceans (DFO)</td>
</tr>
<tr>
<td>Pat Down</td>
<td>Huron County Federation of Agriculture (OFA)</td>
</tr>
<tr>
<td>Don Lobb</td>
<td>Land Improvement Contractors of Ontario (LICO)</td>
</tr>
<tr>
<td>Paul McCallum</td>
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<td>Paul Nairn</td>
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<tr>
<td>Sid Vander Veen</td>
<td>Ontario Ministry of Agriculture and Food (OMAF)</td>
</tr>
<tr>
<td>John Parish</td>
<td>Parish Geomorphic</td>
</tr>
<tr>
<td>Mike DeVos</td>
<td>Spriet Associates</td>
</tr>
<tr>
<td>Jack Imhof</td>
<td>Trout Unlimited Canada</td>
</tr>
</tbody>
</table>
2.2 STEPS TO OBTAINING REFERENCES

References for this literature review were obtained as follows:

1. Several sources were used to provide reference material including committee members/other contacts, university and organizational libraries, government and organizational web sites, and literature databases.

2. The committee provided a list of key words.

3. Key words were combined in a wide assortment of search strings using Boolean logic.

4. Internet links were established with specific libraries and retrieved references were downloaded to a database in Reference Manager® software.

5. The attrition of references during the review process was as follows:
   
<table>
<thead>
<tr>
<th>Reference Type</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Titles Reviewed</td>
<td>~3000</td>
</tr>
<tr>
<td>Titles/Abstracts Retrieved</td>
<td>~260</td>
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<tr>
<td>References Obtained</td>
<td>~110</td>
</tr>
<tr>
<td>References Cited</td>
<td>~35</td>
</tr>
</tbody>
</table>

Additional details are provided in Appendix 3.

3 THE ENCLOSURE OF WATERCOURSES IN AGRICULTURAL LANDSCAPES - DEFICIENCIES IN THE LITERATURE

A thorough search of the literature, based on the key words and guidance provided by the advisory committee, indicated there were several deficiencies in the literature related to the identification of the potential benefits and impacts of enclosing open, surface drains, or watercourses, in agricultural landscapes. In general, there has been little attempt to document the consequences of this practice in agricultural landscapes. Highlights of the findings are listed below:

1. No references identified an interest or concern about the effects of enclosing open drains in agricultural landscapes.

2. It followed that no references focused on the potential benefits and impacts of enclosing open, surface drains, or watercourses in agricultural landscapes.
3. No references specifically identified open drains in agricultural landscapes as headwaters.

4. Several references identified best management practices (BMP) to mitigate the environmental impacts of adjacent agricultural land use and of open drains. These references indicated that BMPs affect many of the same processes/functions that are identified in the body of literature related to river headwater functions, although none of the former references used the specific term ‘headwater functions’.

5. No references compared the characteristics or functions of open drains vs. natural streams although many references compared the headwater functions of natural (often unmanaged forest and related to salmon), agricultural, managed forest and/or urban watersheds (also called catchments). Few of this latter group of references identified or discussed the substructure of the agricultural drainage system i.e. surface and subsurface drainage components, presence of open and enclosed drains, and where the open drains stopped/started and the ‘natural’ watercourses began.

6. Many references discussed the impact of agricultural land use on water quality and quantity.

7. References on municipal drains (a type of open drain in agricultural landscapes) dealt mainly with engineering and maintenance topics associated with open drains.

8. There was no recognition in the literature of open agricultural drains as a location for comparative research.

9. Many references compared the environmental impacts of land uses adjacent to watercourses including forested, urbanized and agricultural uses.

10. Many references compared the effects of channelization or of regulating watercourses in urban and natural streams.

11. Many references discussed river headwater functions (also described as headwater processes) in natural landscapes.

12. Many references discussed research related to the riparian and the hyporheic zones adjacent to headwater streams.

13. The literature related to wetlands provided the clearest categorization of headwater functions.
4 RIVER HEADWATER FUNCTIONS IN NATURAL LANDSCAPES

This section provides a brief review of literature related to river headwater functions in natural landscapes, which in some circumstances may not be directly applicable to agricultural landscapes (Fraser and Fleming, 2001). However, natural landscapes (generally unmanaged forest) represent the standard against which comparisons of headwater functions in other landscapes, including agriculture, often are made (Allan et al., 1997a) (Sponseller et al., 2001) (Thorn et al., 1997). Therefore a review of headwater function, as discussed in the natural biology literature, provides a basis for understanding how these concepts and findings may, or may not, be applied to agricultural landscapes.

4.1 BASIC TERMS AND CONCEPTS

Headwaters represent the initiation of the river continuum as described by Vannote et al., (1980). The river continuum includes several types and orders of streams. Perennial streams flow throughout the year. Intermittent streams do not flow throughout the year but may flow for several months in the year when there is a source of water, for example from snowmelt. Ephemeral streams flow on an irregular basis and generally in response to a specific rainstorm. Perennial, intermittent and ephemeral streams are all types of streams that may form the headwaters of a river continuum (Meyer et al., 2003).

Streams are classified by order depending on their location in the branch-like network of watercourses that converge to form a river continuum (Meyer et al., 2003). A zero-order or ephemeral stream is a depression or hollow that lacks distinct stream banks but still channels water, sediment, nutrients and other material during rainstorms and snowmelt. A first-order stream is the smallest watercourse that has a distinct channel for water flow. For example, water entering a first-order stream may come from a spring or from overland movement. Second-order streams are formed when two first-order streams combine. Third-order streams are formed by the combination of two second-order streams (Meyer et al., 2003) (Plate 3.1).
Plate 3.1: Examples of headwater streams in natural and agricultural landscapes.

<table>
<thead>
<tr>
<th>Natural Landscape</th>
<th>Agricultural Landscape</th>
</tr>
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<tbody>
<tr>
<td><strong>First-Order</strong></td>
<td></td>
</tr>
<tr>
<td>Photograph not available</td>
<td>07/28/2003</td>
</tr>
<tr>
<td><strong>Second-Order</strong></td>
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In a river continuum, the headwaters include the lowest order streams i.e. zero-, first-, and second-order streams, may constitute at least half of the river’s total length and may join the river continuum at any point along its path (Meyer et al., 2003). Allan (1995) provided the following rule: *there are three to four times as many streams of order n-1 as of order n, each of which is less than half as long, and drains somewhat more than one-fifth of the area.*

Headwaters in a river continuum have the greatest contact with adjacent terrestrial areas (Vannote et al., 1980). The two terrestrial zones of contact include the riparian zone and the hyporheic zone. The **riparian zone** is the boundary between land and water and includes the banks of the stream and adjacent vegetation (Giller and Malmqvist, 1998). The riparian zone is a source of allochthonous inputs (resources obtained from outside the stream) such as organic matter in the form of leaf litter. Vegetative cover in the riparian zone, which causes shading over the headwaters, affects temperature and light...
levels in the water. The riparian zone can be very effective in controlling bank erosion and sediment loading to streams. The influence of the riparian zone decreases as the size of the watercourse increases (Giller and Malmqvist, 1998). However, the role of the riparian zone changes too. For example, down river the floodplain becomes the active riparian area and different interactions occur through out flooding and storage (Pers. Com. J. Imhof, 2004).

The **hyporheic zone** is the area of saturated sediments beneath and beside a watercourse. Groundwater and surface water meet in this zone either as an upwelling or downwelling of water (Burton Jr and Pitt, 2002; Meyer et al., 2003). The high level of contact between water and soil creates an environment where many physico-chemical and biological functions of headwaters occur. This zone can provide essential habitat and shelter for all sizes of plants and animals. It can affect contaminant attenuation, removal or transport. Nutrients and carbon are cycled in the hyporheic zone and food web links between primary producers, prey and predators are established (Burton Jr and Pitt, 2002).

The literature reported findings based on a variety of spatial and temporal scales, which had significant impacts on the nature of the findings. **Spatial scales** range from an individual particle to an entire drainage basin, while **temporal scales** range from one day to hundreds of years (Allan, 1995). These concepts were defined by Frissell et al. (1986) in Allan (1995) (Figure 3.2) and by Giller and Malmqvist (1998) (Table 3.1).

Headwaters in a river continuum function as accumulators, processors and transporters of materials from the terrestrial system into the aquatic system (Vannote et al., 1980). Headwater functions *per se* were often viewed as equivalent to headwater processes in the literature (National Research Council (U.S.), 1995) and these two concepts are used interchangeably in this review. Headwaters perform three functions that are broadly categorized as hydrologic, physico-chemical and habitat/food web.
Figure 3.2: An approximate spatial and temporal scale over which physical change takes place in rivers.

(From Frissell et al. (1986) in Allan (1995))

Table 3.1: Variations in space and time that occur at different scales.

(Giller and Malmqvist, 1998)
4.2 HYDROLOGIC
Headwaters fulfill three main hydrologic functions:
1. Maintain water supplies including groundwater recharge
2. Provide natural flood control
3. Trap excess sediment


Water Supply
Headwaters play an important role in the hydrologic cycle and the maintenance of water supplies because they constitute a large proportion of the river continuum and are in close contact with adjacent land (Meyer et al., 2003). The movement of water through the hydrologic cycle is described by several authors (Maaskant et al., 1994) (Allan, 1995) (Dunne and Leopold, 1978). When water reaches the surface of the earth, the generated runoff may follow alternate pathways before it reaches a stream. These pathways include overland flow, groundwater flow, shallow subsurface flow and saturation overland flow (Figure 3.3) (Dunne and Leopold, 1978) (Allan, 1995).

Baseflow, or groundwater recharge, is derived from groundwater that enters a watercourse from the water table. It maintains streamflow when there is no precipitation. Baseflow tends to increase downstream as more groundwater enters the watercourse system (Allan, 1995) (Dunne and Leopold, 1978).

Storm runoff, or direct runoff, occurs when water reaches a watercourse within approximately 24 hours of rainfall. It generally results in a higher rate of water discharge into the watercourse compared to discharge without the influence of precipitation (Dunne and Leopold, 1978).
Dunne and Leopold (1978) suggested that areas in the landscape that are major contributors of storm runoff or groundwater recharge should be identified. Planners and land managers should understand that often the controls of runoff in these areas are very sensitive to disturbance. For example, the conditions causing overland flow during storm runoff occur most often where vegetative cover is minimal or nonexistent e.g. semi-arid rangeland, cultivated fields, compacted soil, dirt roads and paved urban areas (Dunne and Leopold, 1978).

Flood Control
When water enters a natural headwater, its speed is often slowed by the three dimensional tortuosity of the channel, which helps control flooding (Meyer et al., 2003). A natural stream is generally characterized by a rough, uneven channel that is filled with many shapes and sizes of rocks and plants, and by the many twists and turns (called sinuosity)
in its route. The effects of these characteristics on water velocity are depicted by Giller and Malmqvist (1998) and Allan (1995) in Figures 3.4 and 3.5, respectively. These figures also indicate that as a channel becomes smoother or straighter, the speed of the water increases.

Figure 3.4: The effect of three-dimensional tortuosity on the speed of water within a natural stream

(Giller and Malmqvist, 1998)
Figure 3.5: The effect of three-dimensional tortuosity on the speed of water as it travels downstream

(Allan, 1995)

In contrast with the natural stream, when land is developed for urban use, a large percentage of the area is paved or covered by rooftops. When precipitation falls on this impervious cover (IC), overland flow occurs and the resulting water is channeled through curbs and storm sewers to watercourses that are often designed to remove excess water from the area as quickly as possible. Figure 3.6 contrasts the rate of water flow before and after urbanization occurs (Center for Watershed Protection, 2003). The Center for Watershed Protection in Maryland USA has published a review of the impacts of impervious cover (generally attributed to urbanization) on aquatic systems (Center for Watershed Protection, 2003)
Sediment Entrapment

Sediment is eroded and deposited within the river continuum (Figure 3.5) as natural streams meander through the landscape (Allan, 1995). Allan et al. (1997b) published a paper synthesizing ongoing study and management of the Raisin River basin, which drains into Lake Erie from southeastern Michigan. An early study of sediment concentrations under low flow conditions in the basin showed that the upper-basin subcatchments of till geology and mixed land use had the lowest concentrations of sediment in the water. The lower-basin subcatchments with lake plain soils and intensive agriculture had the highest sediment yields. The transport of sediment due to rainfall events was compared for two watercourses within the Raisin River basin. The Iron Creek drains 5300 ha and has a well-forested riparian zone and a natural channel. Forty-five per cent of its watershed is in agricultural production. The Evans Creek drains 7800 ha and was channelized in the 1940s. Sixty-eight per cent of the watershed is in agricultural production. Monitoring sites along its watercourse scored low on biological and habitat assessment protocols. When sediment transport related to specific storm events was monitored, it was found that Iron Creek transported less sediment than Evans Creek. For example, during a storm in November, 1992 the daily sediment yield in Iron Creek was
10 times lower than in Evans Creek even though storm intensity was similar in both watersheds. In March, during the winter, the sediment load was two to five times lower in Iron Creek than in Evans Creek. The authors found that fall and winter storms had the greatest impacts on sediment load due to the intensity of precipitation during these months and the decline in vegetative cover (Allan et al., 1997a).

A simulation of relative impacts of changes in land use/cover around selected, existing forested, agricultural and urban areas in the Saline River subbasin of the Raisin River basin showed that the volume of storm runoff and the yields of sediment, nitrogen and phosphorus were least under forested conditions relative to agricultural and urban conditions (Allan et al., 1997a).

4.3 PHYSICO-CHEMICAL
Headwaters influence the physical and chemical conditions of the watercourse by:
1. Regulating physical conditions e.g. temperature, turbidity
2. Transforming and storing excess nutrients (natural and anthropogenic)

(Meyer et al., 2003)

Work by Maude and Di Maio (1999) and Sponseller et al. (2001) highlighted the importance of the physico-chemical functions of headwaters. Maude and Di Maio (1999) conducted a benchmark study on the Oak Ridges Moraine in central Ontario in the summer of 1992. They collected samples and data from 28 sites on first and second order headwater streams. Sites were chosen that had a well-defined riffle area and were relatively undisturbed by development. The objective of the work was to obtain a ‘snapshot’ representing the spatially broad conditions of the headwater streams in the Oak Ridges Moraine. The results (Table 3.2) could be compared to data from developed areas in the future.
Table 3.2: Physico-chemical status of headwater streams in the Oak Ridges Moraine, Ont.

(Maude and Di Maio, 1999)

The authors provided the following comments on the findings:

- The water temperatures were estimated to lie within 2 °C of maximum daily values, based on unpublished data from a previous study.
- Observed dissolved oxygen was excellent and well above the Ontario Ministry of Environment (MOE) Provincial Water Quality Objective (PWQO) of 54% for cold-water biota.
- The elevated concentrations of chloride ion (above 10%) may be used as an indicator of urbanization since it is used for road de-icing.
- Site pH levels were within the acceptable provincial limits for the protection of aquatic life.
- Phosphorus concentrations were within Interim PWQO (0.03 mg/L) for the elimination of excessive plant growth in rivers and streams at 25 of 28 sites.
• Water collected from all sites contained un-ionized ammonia concentrations that were below the PWQO (0.02 mg/L) for the protection of aquatic life.
• Nitrite concentrations were below the federal guideline for the protection of aquatic life (0.06 mg/L).
• Concentrations of chemicals at the study sites were comparable to the lower values recorded for three local long-term background monitoring stations.
• Hilsenhoff’s biotic index (HBI) scores for water quality resulted in 11 sites rated as excellent with no apparent organic pollution, 12 sites rated as very good with possible slight organic pollution and five sites rated as good with some organic pollution. The authors suggested that the latter two ratings may suggest that natural enrichment from organic sources has occurred. The authors also suggested that the ratings may be inflated due to a lack of detailed taxonomy and the use of generalized tolerance values in the computation of the HBI.

In conclusion, Maude and Di Maio (1999) stated that the benchmark sites in the study, which represented headwater streams, showed water quality that was generally better than applicable water quality standards and supported diverse assemblages of benthic macroinvertebrates including many taxa considered intolerant of pollution.

Studies that compare the impacts of disturbed (e.g. agriculture or urban) vs. non disturbed (e.g. forest) land uses, indicated the relative importance of natural or undisturbed conditions to headwater function. Sponseller et al. (2001) used second and third order headwater streams in the southern Appalachian area to examine differences in physico-chemical features, macroinvertebrate assemblage structure and ecological implications as they related to land use beside the streams and within the watershed. Three watersheds were not developed and six watersheds were developed with some degree of agriculture and/or urbanization. Many of their findings were related to the presence of disturbed land cover/use:
• Total inorganic nitrogen increased as the percentage of non-forested land increased within the catchment level (P=0.02).
• Soluble reactive phosphorus, however, did not differ due to any treatment effect in this study.
• The mean and maximum temperature in forested streams was ~3-6 °C lower than the temperatures in disturbed watershed streams in the study.
• Maximum temperature increased as the percentage of non-forested land increased within all levels of the riparian corridor (P=0.001 to 0.005). The authors agreed with other workers that increases in temperature could be due to lack of shading along unprotected streams or runoff water entering the stream after being heated as it traveled over impervious surfaces in residential areas.
• The mean size of coarse substratum decreased as the percentage of non-forested land increased at the catchment level and all levels of the riparian corridor (P=0.003 to 0.002). The authors suggested that a decline in substratum size was related to an increased incidence of sedimentation due to, for example, agriculture, silviculture and road construction. They also cited work indicating that the presence of a vegetated riparian zone would inhibit the delivery of sediment to streams.
• Chlorophyll a and epilithic standing crop were used to indicate algal growth in the study streams. These indicators increased as temperature and light increased, which was attributed to increases in non-forested land cover in riparian corridors.
• The findings for macroinvertebrate assemblages are discussed in section 4.4.

4.4 HABITAT AND FOOD WEB
Headwaters fulfill two functions related to the maintenance of habitat and food webs:
1. Sustain local and downstream ecosystems by natural recycling ability
   • Store and transform excess organic matter
   • Supply food for local and downstream ecosystems
2. Maintain biological diversity
   • Support diverse habitats, which provide shelter, food, protection from predators, spawning sites and nursery areas, travel corridors through the landscape
   • Support diverse plants, animals and microbial life

Sustain Local And Downstream Ecosystems By Natural Recycling Ability
Organic matter is processed in headwaters either by herbivory or detritivory, which are both primary consumption processes. The former includes primary production and grazing while the latter includes shredding, collecting and detrital decomposition (Fontaine III et al., 1983). Both are similar processes except that herbivory uses autochthonous inputs (resources generated within the stream e.g. aquatic plants) and detritivory uses allochthonous inputs (resources obtained from outside the stream e.g. leaf litter, branches) (Fontaine III et al., 1983).

Aquatic hyphomycetes (a type of fungi) are essential to the decomposition of leaves in streams (detritivory). Sridhar and Barlocher (2000) determined that these organisms, while living on maple leaves, decreased the mass of the leaves and increased their own mass as concentration of N and P increased. These findings were reflected in both laboratory and first order headwater streams. The findings suggested that fungal production in streams, and, by extension, production of invertebrates and higher tropic levels which are further along the food chain, is stimulated by inorganic N and P (Sridhar and Barlocher, 2000).

The organic compounds that make up allochthonous input materials serve as energy sources that may be used locally or downstream (Vannote et al., 1980). Wallace et al. (1999) measured the export of organic matter from a forested headwater stream in North Carolina over 9.5 years. These workers found a strong relationship (P<0.001) between leaf litter export and maximum storm discharge. The impact of storm runoff dislodged organisms and disrupted food sources, which, the authors suggested, could affect long-term abundance, biomass and productivity of benthic communities. The authors went on to suggest that human activities that alter storm flow frequency and intensity would have a similar effect (Wallace et al., 1999). Vannote et al. (1980) also postulated that, in fact, downstream communities are structured to capitalize on the inefficiencies of upstream processing.

When allochthonous inputs (leaves, wood) were severely restricted (~95 %) in a forested headwater stream in North Carolina for four years, invertebrates in the treatment stream
were reduced 76% in abundance, 78% in biomass and 78% in productivity compared with measurements taken before the treatment was imposed (Wallace et al., 1999). This study clearly showed the importance of headwaters in storing and transforming organic matter, and in supplying food for the local ecosystem.

The objective of work by Wipfli and Gregovich (2002) was to assess the potential subsidy of energy from fishless headwaters to downstream systems containing fish. Fifty-two headwater streams from forested areas in Alaska were sampled regularly for aquatic and terrestrial invertebrates, and coarse organic detritus. Aquatic species made up 65 to 92% of the total invertebrates captured. Invertebrates and detritus were exported from the headwaters throughout the year. The authors estimated that 0.44 g dry mass/m²/yr of invertebrates from fishless headwaters was delivered downstream to habitats containing fish. They also estimated that every kilometer of stream containing salmonids (a type of fish) could receive enough prey (invertebrates) and detritus from its upstream headwaters to support 100-2000 young-of-the-year (YOY) salmonids (Wipfli and Gregovich, 2002).

The complexity and hierarchal nature of the food web was demonstrated by Wallace et al. (1999) in their study of a forested headwater stream in North Carolina. These workers showed a strong ‘bottom-up’ effect of leaf litter (detritus) on the abundance and production of primary consumers (prey) which was subsequently echoed by secondary consumers (predators). Thus, headwaters, which have the greatest opportunity in the river continuum to receive allochthonous inputs due to their close and intimate proximity to adjacent riparian zones, function as the environmental substrate for food web function.

Kawaguchi and Nakano (2001) examined the contribution of terrestrial invertebrates from forest (n=2) and grassland (n=2) sites to the diets of salmonids in a Japanese headwater stream. Forty-nine and 53% of the annual total prey consumption by salmonids in the forested and grassland areas, respectively, consisted of terrestrial invertebrates.
Macroinvertebrates function as grazers, shredders, gatherers, filterers and predators in stream ecosystems. Headwaters represent a major environment in which these organisms transform and store organic matter. Wallace and Webster (1996) provide details on the function of each group in their review paper *The Role of Macroinvertebrates in Stream Ecosystem Function*. Malmqvist (2002) also reviewed the patterns and processes in the river continuum that relate to aquatic invertebrates. He included a discussion on the distribution and dispersal of invertebrates, their affect on the cycling of nutrients and carbon, and the need for future study.

**Maintain Biological Diversity**

Allan (1995) stated the general rule that *diversity and abundance* (of organisms) *increase with substrate stability and the presence of organic detritus*. Other factors involved include mean particle size of mineral substrates, the range of sizes and surface texture. Table 3.3 shows the results from one study discussed by Allan (1995), which shows that the abundance of species varied across substrate type and that it was highest on organic based substrates.

Table 3.3: Effect of substrate type on abundance and species diversity.

<table>
<thead>
<tr>
<th>Habitat</th>
<th>Abundance (No. m⁻²)</th>
<th>No. of Species</th>
<th>Diversity a</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand</td>
<td>920</td>
<td>61</td>
<td>1.96</td>
</tr>
<tr>
<td>Gravel</td>
<td>1300</td>
<td>82</td>
<td>2.31</td>
</tr>
<tr>
<td>Cobble and pebbles</td>
<td>2130</td>
<td>76</td>
<td>2.02</td>
</tr>
<tr>
<td>Leaves</td>
<td>3480</td>
<td>92</td>
<td>2.40</td>
</tr>
<tr>
<td>Detritus b</td>
<td>5680</td>
<td>66</td>
<td>1.73</td>
</tr>
</tbody>
</table>

a Diversity = (S − 1)/log₂ N
b Finely divided leaf material in pools and along stream margins.

(Allan, 1995)
Successful restoration of habitat serves to underline the importance of headwater streams and the effects of adjacent land use/cover. In their review of trout stream management in southeast Minnesota, Thorn et al. (1997) showed that the affected streams were severely degraded due to the impact of agricultural production on adjacent lands. Up to the 1970s, after many years of rehabilitation, the continued lack of adult fish habitat within the streams had limited trout abundance. Additional rehabilitation of the streams eventually improved the abundance of brown trout in the streams and lead to recommendations on the desired abundance of important habitat variables in streams (Table 3.4) (Thorn et al., 1997).

Table 3.4: The components of the habitat function provided by headwater streams.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Abbreviation</th>
<th>Recommended abundance or range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overhead bank cover (%)</td>
<td>OBC</td>
<td>2</td>
</tr>
<tr>
<td>Instream rock cover (%)</td>
<td>IR</td>
<td>1–2</td>
</tr>
<tr>
<td>Riprap cover (%)</td>
<td>RR</td>
<td>1</td>
</tr>
<tr>
<td>Overhead cover (%)</td>
<td>OC</td>
<td>10</td>
</tr>
<tr>
<td>Debris cover (%)</td>
<td>DEB</td>
<td>5</td>
</tr>
<tr>
<td>Total cover (%)</td>
<td>TC</td>
<td>20</td>
</tr>
<tr>
<td>Length of OBC/thalweg length (%)</td>
<td>L_OBC/T</td>
<td>20</td>
</tr>
<tr>
<td>Area of water deeper than 60 cm (%)</td>
<td>D60</td>
<td>25</td>
</tr>
<tr>
<td>Pool bank shade (%)</td>
<td>PBS</td>
<td>75</td>
</tr>
<tr>
<td>Pool length to stream reach length (%)</td>
<td>PL</td>
<td>75</td>
</tr>
<tr>
<td>Gradient (m/km)</td>
<td>GRAD</td>
<td>5–7</td>
</tr>
<tr>
<td>Velocity (cm/s)</td>
<td>VEL</td>
<td>15–25</td>
</tr>
</tbody>
</table>

* When necessary for erosion control.  
* Sum of OBC, IR, RR, OC, DEB.

(Thorn et al., 1997)

Various methods of assessing the quality of habitat and biological diversity have been used. A habitat index developed by Michigan Department of Natural Resources (1991) and an Index of Biotic Integrity (IBI) published by J. R. Karr (1991) were used in the Raisin River basin project to determine relative habitat quality and biological assemblage composition in selected areas of the basin. The northern and western headwater streams,
characterized by more area in forest and wetlands, and less area in agriculture, scored the highest values for both indices (Allan et al., 1997a). The study also provided evidence to support the hypothesis that intensive agricultural land use has a negative impact on stream habitat which translates into a negative impact on fish fauna (Allan et al., 1997a).

A study on the importance of species to ecosystem function as it relates to biological diversity was devised by Jonsson et al. (2002). Stream-living macroinvertebrate shedder species (Insecta: Plecoptera and Trichoptera; Crustacea: Amphipoda) were removed from field microcosms in a sequence that simulated impacts from two human activities (anthropogenic perturbations) i.e. acidification and organic pollution. These workers found that type of detritus (beech vs. alder leaves) and the combination of species affected the rate of leaf breakdown. When species were combined in groups of two or three, the loss of a single species in the combination decreased the rate of breakdown. It was found that species complemented each other in their ability to breakdown detritus. For example, one species fed on the surface of the leaf, one fed on the edges and the third cut the leaves into smaller pieces. The third species, Sericostoma personatum (Kirby & Spence) (Trichoptera), was particularly important when the detritus was of lower quality i.e. beech leaves. This species cut up the leaves and made more pieces available for the species feeding on the surfaces and edges of the leaves (Jonsson et al., 2002).

As indicated in earlier sections, studies that compare the impacts of disturbed vs. non disturbed land uses (often agriculture or urbanization vs. forest), indicate the relative importance of natural or undisturbed conditions to headwater function. Wang et al., (2003) studied the effects of urbanization on fish assemblages, physical habitat, baseflow and water temperature at 39 sites in small coldwater trout streams in Wisconsin and Minnesota. As the percentage of connected imperviousness, e.g. roadways, increased above six per cent, assessment indices decreased and were predictably low when the percentage of connected imperviousness rose above 11 %. Land cover within 30 m of the stream explained more of the variance in fish assemblages and instream habitat and physical conditions than land cover beyond 30 m. The authors concluded that even low levels of urban development can damage coldwater stream systems (Wang et al., 2003).
The work of Sponseller et al. (2001) was discussed earlier. Their findings also indicated effects on biological diversity:

- Sites with forested land cover in the riparian sub-corridor had the most diverse and even macroinvertebrate assemblages among the streams in the study. The authors suggested that local conditions were very important to local invertebrate assemblages and may even have a positive influence downstream. They went on to suggest that patches of forested land (woodlots) within a mixed use watershed area were critical to the distribution of many species of macroinvertebrates.

- The effects of temperature and light on the findings for chlorophyll a and epilithic standing crop as indicators of algal growth are discussed earlier in section 4.3.

Kawaguchi and Nakano (2001) found in their study of a Japanese headwater stream that differences in the riparian vegetation (forest or grassland) along the headwater stream affected the input of terrestrial invertebrates as a source of food. They suggested that this could play an important role in determining the local distribution of salmonids in the stream.

5 DRAINAGE SYSTEMS IN AGRICULTURAL LANDSCAPES

5.1 PURPOSE AND TYPES
Drainage systems on agricultural lands remove excess water from the soil surface and/or the soil profile of wet cropland, which creates an aerated root zone and enhances plant uptake of nutrients (Zucker and Brown, 1998). In general, drainage controls the water table and field wetness, which optimizes soil conditions for cultivation and plant growth (Irwin, 1997). An agricultural land drainage system includes surface (e.g. land smoothing, grassed waterways, open ditches) and/or subsurface drainage (i.e. drainage pipe installed at a specified soil depth) components (Irwin, 1997) (Zucker and Brown, 1998). The Handbook of Drainage Principles (Irwin, 1997) provides an overview of
agricultural drainage in Ontario including identification of the need for drainage, benefits, methods and advice on the development of an agricultural drainage system.

Surface and subsurface agricultural drainage systems have been installed across Ontario and in many parts of North America (Skaggs et al., 1994) (Fraser and Fleming, 2001) (Plate 4.1)

Plate 4.1: Aerial view of surface water flow path and lay out of subsurface drainage system.

Open surface drains or ditches, along with other watercourses, channel surface water and subsurface tile water from agricultural and other land into the river continuum (Irwin, 1997; Zucker and Brown, 1998). In Ontario, open or enclosed drains that collect water from drainage systems on agricultural and other lands are identified by their legal status.

These drains may be designated as follows:

<table>
<thead>
<tr>
<th>Type of Drain</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Municipal</td>
<td>Created under the authority of the Drainage Act in Ontario; may involve one or more landowners</td>
</tr>
<tr>
<td>Private</td>
<td>Constructed by a private landowner on their property</td>
</tr>
</tbody>
</table>

(Maaskant et al., 1994)
Mutual Agreement: Private drains constructed through an agreement between two or more landowners

Award: Created under the Ditches and Watercourses Act, in effect up to 1963

(Evanitski, 2000).

Plates 4.2 to 4.4 show well-managed open and enclosed drains within an agricultural landscape. Open drains carry water during low and high flow conditions. Enclosed drains carry water during low flow conditions and swales or grassed waterways on the surface of the soil above enclosed drains carry excess water during high flow conditions e.g. significant rainfall events (Pers. Com. M. DeVos, 2004).

Plate 4.2: Well vegetated and buffered, open agricultural drain.

Plate 4.3: Well maintained open agricultural drain.

Plate 4.4: Well maintained enclosed agricultural drain.
5.2 IMPACTS OF AGRICULTURAL DRAINAGE

At least three reviews of the impacts of agricultural drainage were published during the last decade (Skaggs et al., 1994) (Fraser and Fleming, 2001) (Rudy, 2004). Skaggs et al. (1994) determined that agricultural drainage can impact receiving waters, first, when lands are converted to agricultural production and, second, when drainage systems on existing agricultural lands are improved, generally by increasing the intensity of the subsurface components of the drainage systems. These workers noted that it was difficult to separate the environmental impacts of changes in land use from changes due to natural vs. artificial drainage. Their review showed that the conversion of natural landscapes to agricultural production generally increased peak runoff rates, sediment losses and nutrient losses, although exceptions occurred. Conversion to agricultural production was often criticized for causing loss of and negative impacts on wildlife habitats along with declines in the natural ability of the landscape to filter or cleanse water (Skaggs et al., 1994). In contrast, improved subsurface drainage in agricultural landscapes generally decreased peak outflow rate and sediment loss. The loss of some pollutants increased (e.g. nitrates and soluble salts) while the loss of others decreased (e.g. phosphorus and organic-nitrogen) (Skaggs et al., 1994). Exceptions to these findings occurred in the literature.

Fraser and Fleming (2001) also concluded from their review of the environmental benefits of tile drainage (i.e. focused on in-field systems) that peak flow volumes were decreased in watercourses associated with artificially drained land, that total runoff of water was spread out more over time and that surface runoff may be reduced. However, the volume of annual total runoff was greater in watersheds with tile drainage than in watersheds with only surface drainage systems. In agricultural landscapes the presence of tile drainage generally decreased surface soil erosion, which decreased the load of sediment, some nutrients (e.g. phosphorus, potassium) and some pesticides (e.g. atrazine) entering nearby watercourses (Fraser and Fleming, 2001). This review of the literature showed that, similar to the findings reported earlier by Skaggs et al. (1994), nitrate-nitrogen losses from tile drained fields tended to be greater compared to non tile drained fields (Fraser and Fleming, 2001).
A review of positive and negative environmental impacts related to agricultural drains was provided recently by Rudy (2004). Many findings were similar to Skaggs et al. (1994) and Fraser and Fleming (2001) and are not repeated here. As described by Skaggs et al. (1994), improved subsurface drainage occurs on a regular basis within agricultural landscapes. Rudy (2004) noted that in some circumstances agricultural drainage will increase, not decrease, peak flows. For example, increasing the frequency of subsurface tile drains within a field, e.g. from 60 ft to 30 ft spacing, increased total flow by 50%. Enlarging, straightening and cleaning debris from surface channels (i.e. open drains or channelized streams) also increased the peak flow by 100-200% at the watershed outlet. However, the literature reviewed by Rudy (2004) showed that subsurface drainage systems had no effect on volume of water flowing downstream. This was attributed to the increased water storage capacity of land with subsurface drainage systems, which spreads out the effects of peak flows from storms.

Evanitski (2000) suggested that, over time, constructed drains begin to look like natural streams as sediment builds up and vegetation along the banks and in the watercourse grows and matures. Maintenance, repairs or improvements to the drain may be required to ensure that the drain continues to fulfill its original function of removing excess water from agricultural land (Evanitski, 2000). Several publications suggested that using best management practices (BMPs) while carrying out these activities would minimize potential negative impacts on the environment (Thames River Implementation Com, 1982) (Maaskant et al., 1994) (Evanitski, 2000).

6 CONCLUSIONS

This review determined that the enclosure of surface watercourses in agricultural landscapes and the potential impacts of this practice on the environmental health of watersheds have not been addressed by the scientific community or other stakeholders. Therefore, it was not possible to determine whether this practice was beneficial, detrimental or benign from an environmental perspective.
A brief review of literature related to river headwater functions in natural landscapes showed that many workers chose undisturbed, often forested, landscapes within which to conduct their studies. The findings from these studies may, or may not, be directly applicable to agricultural landscapes since agricultural landscapes are highly disturbed by human activity. Agricultural landscapes are and will continue to be an essential component of food production. Therefore, like natural landscapes, agricultural landscapes represent a standard land use within which comparisons of the headwater functions in natural watercourses, open drains and enclosed drains should be made.

The literature related to the impacts of agricultural drainage discussed many topics associated with headwater functions in natural landscapes but it was clear that the workers did not view the information from this perspective. Most of these workers studied the non target or off site impacts of adjacent land use and/or drainage on hydrologic and physico-chemical characteristics of water in various locations within agricultural landscapes. The literature on headwater functions in natural landscapes often used agricultural watersheds for comparative purposes but it was clear that these workers did not view agricultural landscapes as a standard landscape within which to conduct research on headwater functions.

It is important to recognize that whatever practices are necessary to produce food, they must ensure that agricultural sustainability is achieved by meeting environmental, economical and societal needs. This document presents information from an environmental perspective.

7 RECOMMENDATIONS

7.1 PROPOSED ACTION

1. Funding to conduct a complementary literature review and develop a searchable database was requested and received from the Agricultural Adaptation Council by the Huron County Farm Environmental Coalition (HCFEC). The work will focus on the
economic benefits of tile and open ditch drainage to agricultural production in Ontario with special emphasis on the economic impact of replacing open drains/watercourses with tile.

2. A member of the advisory committee will present the findings of the review discussed herein at the 2004 annual meeting of the Soil and Water Conservation Society.

3. Funding should be sought to obtain the answers to the questions posed in the following subsection.

4. The scientific community should be encouraged to pursue the research questions posed in the following subsection.

5. The practice of enclosure of watercourses should be further characterized. For example, the incidence, size and capacity of enclosures should be summarized. Pictures of different sizes of streams that have been enclosed would be helpful. The difference between drains that were enclosed in the original design of the drainage system and drains that were initially open to the surface and then enclosed some time after they were first installed should be accounted for. This approach would refine any estimate of the rate of enclosure of open drains or watercourses.

7.2 FUTURE RESEARCH

The advisory committee agreed that to evaluate the potential benefits and impacts of enclosing open, surface drains, or watercourses, in agricultural landscapes the following questions should be addressed through further research:

1. a) Do open drains perform headwater functions and, if so, how well?
   b) How do headwater functions compare between natural streams and trapezoidal channels?
2. Do enclosed drains perform headwater functions and, if so, how well?
3. How do woodlots and best management practices (BMPs) affect headwater functions in natural watercourses, open drains and enclosed drains?
4. Does enclosure affect the health of the local and downstream environments?
5. a) What are the impacts of the surrounding land use on headwater functions?
   b) What are the impacts of enclosing drains compared to the impacts of the
   surrounding land use on headwater functions?

   It is anticipated that relevant research would examine:
   • The localized effects of enclosing one drain compared to the cumulative effects of
     enclosing many drains within a watershed;
   • The impacts of enclosing drains within the context of the physical conditions in the
     area e.g. soil, precipitation, proximity to springs and cropping practices;
   • The implications of enclosing drains for fish communities, fish habitat and the
     environmental health of the watershed; and
   • The impacts of changes in headwater ‘structure’, i.e. natural vs. channelized vs.
     enclosed, and land use, i.e. natural vs. agriculture vs. urban, in natural, agricultural
     and urban watersheds in Ontario.
REFERENCES


Prepared by Jane Sadler Richards PhD PAg, Cordner Science


APPENDIX 1: Terms of Reference

The transformation of open, surface agricultural drains to closed, tiled drains is occurring across southern Ontario. In one example, a preliminary analysis of the number of drains enclosed between 1975 and 1999 in one sub-basin of the Ausable River indicated that 14% of open drains were transformed during this time period. The impact on direct or indirect fish habitat and to the overall health of the watershed and ecosystem is not clearly understood. Some potential effects of drain enclosure may include changes to water temperatures, sediment deposition, reduction of autochthonous and allochthonous inputs of organic matter and fish habitat. A literature review of the potential benefits and impacts of enclosing open, surface drains, or watercourses are a necessary first step in evaluating this practice.

Proposed Project – Literature Review

The literature review will include a general search followed by the selection and review of information most applicable to the concerns about the transformation of open, surface agricultural drains to closed, tiled drains. The review should be conducted with primary and grey literature. Characteristics that should be examined include the following that may be beneficial or detrimental:

- Sediment inputs to a water course
- Water temperatures
- Water quality (total phosphorus, nitrates, etc. but also turbidity)
- Allochthonous and autochthonous inputs
- Fish habitat
- Hydrologic consequences

In light of these potential changes, implications for fish communities, fish habitat and the health of the watershed should be described.

Other factors that should be considered in the literature review are the effects of the practice on a case-by-case basis compared to cumulative effects of many closures in one sub-basin. Some comment on the enclosure of natural water courses vs. artificially constructed channels. These might be considered differently as landowners and municipalities who have paid to construct these watercourses tend to claim some ownership. Finally, the review should consider impacts of the closure in relation to key physical conditions in the area (e.g., soil, precipitation, proximity to springs) and cropping practices.

As part of the literature review a number of individuals and organizations will be contacted. However the review is not limited to the following:

US Army Corp of Engineers
US Department of Agriculture
US Environmental Protection Agency
DFO - specifically Central & Arctic Region

Prepared by Jane Sadler Richards PhD PAg, Cordner Science
Agriculture and Agri-Food Canada
Provincial/state and federal agencies across North America (note that some of the above sources would be captured in this statement)
Universities across North America
internet/web search
Derrick Beach, Program Services Branch, Ontario Great Lakes Area, DFO Burlington - phone (905) 336-4435

The project will include a written report that sets out the procedure used and findings. The consultant will provide one hard copy of the report as well as one electronic/digital copy.

A draft literature review is required for March 1.
APPENDIX 2: Committee Meeting Notes

Tile-Ins Meeting # 1
9:30 am–2:00 pm January 14, 2004

Present:

<table>
<thead>
<tr>
<th>Name</th>
<th>Affiliation</th>
<th>Phone</th>
<th>Email</th>
</tr>
</thead>
<tbody>
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<td>Pat Down</td>
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</tr>
</tbody>
</table>

Regrets
Jack Imhof, Trout Unlimited, Canada, (519) 824-4120 X53608, jimhof@tucanada.org
Sid Vander Veen, OMAF, (519) 826-3552, sid.vanderveen@omaf.gov.on.ca

1. Introduction
Tom Prout welcomed everyone and explained why it was necessary to have a technical committee for this literature review. The ABCA felt that if many stakeholders were involved in setting the terms of reference and evaluating the literature review, that the findings would be more complete, credible and acceptable by the different groups.

2. Headwater Streams: Form and Function
Mari Veliz provided some definitions and information about the function of small streams. She defined perennial as streams that flow year round, intermittent as streams that flow several months of the year, and ephemeral as systems that flow in response to a specific rain event. (There was some discussion about whether ephemeral systems should be considered streams. It was agreed that they were not streams, as they lacked a bed and a bank, but they did convey water, sediment and nutrients.) The stream order classification was described and the concept of a zero order stream, or an ephemeral system was introduced. Mari also explained that due to the physical contact the water had with the channel in the low (zero, first and second) order streams, these systems had ecosystem functions. In particular, low order streams have hydrologic function; they
retain water. These areas produce sediment but may also retain sediment. The headwater areas are also thought to be important for carbon input (e.g., leaves) and nutrient cycling.

Potential effects of the enclosure of open watercourses were described. Factors that may be affected by enclosure included changes to: water quantity, water quality (sediment and nutrient concentrations), water temperature, introduction of material and habitat. (Mike DeVos described the importance of sediment transport. Natural systems convey sediment and those watercourses that drain agriculturally altered landscapes may have increased sediment loads.) Headwater systems typically comprise 50 to 80% of the length of the river. The water quality in these systems is therefore, quite important to the entire river network.

Norm Smith explained that the DFO is interested in the contribution that first order streams make to fish habitat and to the overall health of the watercourse. He explained that there are inputs of energy (carbon) and sediment in first order streams and that these processes are important to the downstream system. He likened the watershed to a tree. The fourth and fifth order channel is the trunk and the smaller tributaries the branches and twigs. How much can be pruned before the trunk is impaired? Eventually a workshop should be organized and speakers should be invited to present information about headwater systems.

3. DRAFT - Terms of Reference (Review)
Jane Sadler-Richards asked if the literature review was about the role of headwater ecosystems or the effects of closures. John Parish and Norm Smith suggested that the focus should reflect what is found in the literature. There may not be much information about this specific topic and that there might be more information about the function of headwater systems. The implications of enclosure for headwater systems might have to be interpolated.

Norm Smith asked about the format of the review, would it be a literature review or an annotated bibliography? Jane Sadler-Richards described the differences between the two formats. A literature review is a summary with a thesis and is referenced. An annotated bibliography would document key points for each paper. An annotated bibliography would be more time consuming and would limit the number of papers that could be reviewed. It was decided to conduct a literature review and an annotated bibliography would be done if there were enough time, or might be done at a later date.

Pat Down wondered about the economic impacts of drainage. It was agreed that this was a topic worthy of investigation but the focus of this particular review would be biological and hydrologic effects of enclosure.

4. Acceptable Literature for Review
‘Cast a broad net’, was a term used frequently during this discussion. John Parish suggested that one potential problem with the primary literature is that headwater stream processes are not frequently quantified in the current literature.
Applicable references from the 1960’s and 1970’s will be reviewed. The literature review will not be limited to references from North America. Don Lobb provided Ron Fleming’s recent literature review.

50 key words: agriculture, tiles, water quality, rural, economic, ditch, drain, pipe, headwater, nutrient, allochthonous, channel, slough, stream, municipal hydrologic, sediment, temperature, fish, fish habitat, drainage, intermittent, ephemeral, soil/water interface, first order, zero order, constructed/straightened, lotic ecology, enclosure, tile-in, close-in, buried, rills, storm water management, benefit/impacts, erosion, stream ecosystem, fluvial geomorphology.

Jane Sadler Richards wondered if OMAF had the number of drains that had been closed. It might be an important statistic to add to the introduction of the literature review. Mike DeVos suggested that the original landscape should be recognized (i.e., some drains were never open in the first place).

**Sid, do you know the number of drains that have been closed (in Ontario, or Middlesex County)?**

5. **Summary**
Jane summarized that the review would discuss the impacts and benefits of closing in first order and ephemeral natural, or man-made water courses. Information from 1950 to present would be reviewed. Global information would be reviewed, however the review would focus on studies conducted in a similar landscape. The aforementioned key words would be used. Effects of enclosure would be the first theme. If there is not much information about this topic than she will look at the function of headwaters. Mike DeVos suggested that Jane might find more on natural water courses and not much on constructed water courses. It was agreed that there would likely be holes, which would identify further questions about this issue.

Jane said the literature review procedure would be documented. She planned to visit University of Guelph and Western libraries. She would use the Internet to look at specific web sites (e.g., the USDA).

Norm Smith suggested that the identification of the absence of information might also be an important finding and that a session at the upcoming “Channel Symposium” in Ottawa, next fall might be organized.

Another project that should be pursued is the economic benefits of tile drainage.

6. **Lunch**
Meeting was adjourned at 1:30 pm. Mari Veliz took notes. Please submit any corrections to her.
APPENDIX 3: Details of Search Method

The steps and outcomes of the steps are list below:

1. The options for external library search through Reference Manage® software were reviewed. This software has pre programmed links that allow a search of over 100 libraries world wide (called Z39.50 sites). A test of these links, however, revealed that they provide limited access to library resources compared to a direct link with individual libraries. For this reason, links were established with specific libraries without the assistance of Reference Manager® software. Retrieved references were downloaded to a database in Reference Manager® software.

2. A key word search was conducted using Boolean logic to combine concepts. Boolean connectors included AND, OR and NOT. Special characters to indicate phrases (“ “), truncation (*), wildcards (?) and ( ) for grouping were used appropriately to ensure that the search included all possible formats of words. (Characters sometimes changed between sources.)

3. The committee provided a list of key words and phrases as follows:

<table>
<thead>
<tr>
<th>agriculture</th>
<th>lotic ecology</th>
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<tbody>
<tr>
<td>allochthonous</td>
<td>municipal</td>
</tr>
<tr>
<td>benefit/impacts</td>
<td>nutrient</td>
</tr>
<tr>
<td>buried</td>
<td>open ditch</td>
</tr>
<tr>
<td>channel</td>
<td>pipe</td>
</tr>
<tr>
<td>close-in</td>
<td>quality</td>
</tr>
<tr>
<td>conduit</td>
<td>quantity</td>
</tr>
<tr>
<td>constructed/staightened</td>
<td>rills</td>
</tr>
<tr>
<td>ditch</td>
<td>rural</td>
</tr>
<tr>
<td>drain</td>
<td>sediment</td>
</tr>
<tr>
<td>drainage</td>
<td>sewer</td>
</tr>
<tr>
<td>economic</td>
<td>slough</td>
</tr>
<tr>
<td>enclosure</td>
<td>soil/water interface</td>
</tr>
<tr>
<td>ephemeral</td>
<td>stormwater management</td>
</tr>
<tr>
<td>erosion</td>
<td>stream</td>
</tr>
<tr>
<td>first order</td>
<td>stream ecosystem</td>
</tr>
<tr>
<td>fish</td>
<td>surface drain</td>
</tr>
<tr>
<td>fish habitat</td>
<td>temperature</td>
</tr>
<tr>
<td>fluvial geomorphology</td>
<td>tile-in</td>
</tr>
<tr>
<td>habitat</td>
<td>tiles</td>
</tr>
<tr>
<td>headwater</td>
<td>watercourse</td>
</tr>
<tr>
<td>headwater</td>
<td>water quality</td>
</tr>
</tbody>
</table>
4. Key words were combined in search strings similar to examples listed below:

| 1 | drain* OR ditch* OR stream* OR water*course* |
|   | AND tile*in* OR bur* OR under*ground* OR clos* |
|   | AND environ* OR water*shed* OR eco* |
| 2 | drain* OR agricult* |
|   | AND environ* OR habitat* OR eco* |

5. The following sources provided reference material or were electronically searched:

<table>
<thead>
<tr>
<th>Committee Members</th>
<th>J. Imhof</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>D. Lobb</td>
</tr>
<tr>
<td></td>
<td>J. Sadler Richards</td>
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<td></td>
<td>S. Vander Veen</td>
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<tr>
<td></td>
<td>M. Veliz</td>
</tr>
<tr>
<td>Databases</td>
<td>BioSis Previews (formerly Biological Abstracts)</td>
</tr>
<tr>
<td></td>
<td>CISTI Source</td>
</tr>
<tr>
<td></td>
<td>ISI Web of Science</td>
</tr>
<tr>
<td>Libraries</td>
<td>Canadian Agricultural Library</td>
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<td>Sir Wilfred Laurier University</td>
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<td>Univ. of Western Ontario</td>
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<td>Univ. of Waterloo</td>
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<tr>
<td>Web Sites</td>
<td>Canadian government</td>
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<td></td>
<td>Ont. Min. of Agriculture and Food</td>
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<td></td>
<td>Ont. Min. Environment</td>
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<tr>
<td></td>
<td>Ont. Soil and Crop Improvement Assoc.</td>
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<td></td>
<td>United States government</td>
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</tbody>
</table>

6. The attrition of references during the review process is indicated below:

| Titles Reviewed | ~3000 |
| Titles/Abstracts Retrieved | ~260 |
| References Obtained (includes ~50 provided by committee members) | ~110 |
| References Cited (draft) | ~35 |