Analysis of Drainage Mitigation Policy Outcomes for Saskatchewan

Prepared by Saskatchewan Conservation and Development Association

For Water Security Agency

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Project Background

The project fills gaps in the Saskatchewan Water Security Agency's policy analysis for the development of stewardship policy. The project analyses the impact of wetland drainage on downstream flooding, groundwater supply, downstream water quality and wildlife habitat and determine the level of mitigation achieved by various levels of wetland retention or use of beneficial management practices (BMPs).

WSA has developed procedures and policies to assess project risk to downstream flooding, water quality and habitat loss of projects at the network scale. These projects necessarily need to be evaluated at the network (landscape scale) rather than the individual wetland since projects are constructed by connecting many wetlands by drainage works. Project attributes such as size and location are used to assess impact and drive mitigation requirements. For example, wetland consolidation projects are considered lower risk and have significantly lower mitigation requirements than drainage projects which drain to a natural creek. High risk projects are currently required to utilize flow controls and control erosion however these measures alone are insufficient to manage the impacts of wetland drainage. Additional mitigation requirements are needed to address these impacts including wetland retention.

Project Overview A team of experts in hydrology, water quality, and wildlife was assembled to assess the environmental outcomes of various levels of wetland retention or use of BMPs. These are referred to subsequently as the specialists.

The objective was to derive clear, concise and justifiable options for mitigation policy with clearly articulated environmental outcomes of each option.

Experts

1. Hydrology - Dr. Holly Annand – Associated Engineering
2. Water Quality – Dwight Williamson
3. Effects on Wildlife – Dr. Robert Clark
4. Effects on Groundwater - Garth van der Kamp and David Milo Ferris

The scope of this project focused on the impacts of drainage however, stakeholders have raised several possible environmental benefits from wetland drainage including less fuel and agricultural input use from increased field efficiency and improved soil health/productivity. These components have been addressed in a separate report, PAMI (2022), which demonstrated substantial decreases in mechanical overlap/nuisance costs and increases in crop productivity with wetland drainage. Pattison-Williams and Klotz (2022) likewise demonstrated the increase in economic growth that could be facilitated with continued drainage development.

Pattison-Williams, J.K. and A. Klotz. 2022. An Economic Threshold Analysis of Wetland Drainage in Saskatchewan. Research report produced for the Saskatchewan Research Council by Pattison Resource Consulting Ltd. (PRC), Canada.

Prairie Agricultural Machinery Institute (PAMI). 2022. Refining economic and agronomic costs of wetland mitigation. 82pp.

Summary of Work (extracted from summary/abstract of each expert's reports)

1 Hydrology – Holly Annand – Associated Engineering

The Saskatchewan Conservation and Development Association (SCDA) retained a group of specialists in hydrology, water quality and wildlife ecology to assess the potential impact of wetland drainage on downstream flooding, downstream water quality, and wildlife habitat/population, respectively. Each specialist's report is intended to assist the Water Security Agency (WSA) in developing a wetland mitigation policy for the Province of Saskatchewan. Together, the specialists developed a set of wetland retention scenarios that included 10% decrements in wetland area from historical maximums, the current wetland area, and a floor scenario that prevented drainage on protected lands or soils with poor agriculture capability. The specialists then assessed the potential environmental impacts of the wetland retention scenarios on indicators related to their area of specialization. WSA provided and processed the data used in this study, which included Canadian Wetland Inventory (CWI), land use, soil capability, and protected areas, divided into quarter sections. The study area was limited to the extent of CWI coverage in Saskatchewan (approximately 40 million acres or 150,000 km^2). The work presented in this report is specific to the hydrology and flooding component of the project. The audience is assumed to have some technical knowledge of prairie hydrology.

The Contributing Drainage Area (CDA) method was used to predict the impact of wetland retention scenarios on runoff volumes for major and sub-sub basins within the study area. CWI coverage was nearly complete for areas of the Assiniboine, Qu'Appelle, and Souris river basins within Saskatchewan, which allowed for broad-scale estimates of the impact of wetland drainage in these major basins. More detailed estimates were possible for 36 sub-sub basins within the study area that had full or partial CWI coverage to support using the CDA method. General estimates of the impact of wetland retention scenarios on instantaneous peak flows were made based on log-log relationships between Effective Drainage Area (EDA) and instantaneous peak flow. Several limitations of the CDA method and CWI dataset used to complete this study are discussed within this report. Overall, the use of the CDA method and CWI dataset likely underestimated the impacts of wetland loss on streamflow in Saskatchewan due to the large spatial domain that needed to be analyzed in this project.

The Assiniboine, Qu'Appelle, and Souris river basins responded similarly to the series of wetland retention scenarios considered in this study, although sub-sub basin results varied within these major basins. The key results in these major basins include:

- 80% wetland area retention was predicted to increase runoff volumes by approximately 40 to 45% for events with 1:2 year return periods, 10 to 15% for events with 1:10 year return periods, and 3 or 4% for events with 1:100 year return periods. Instantaneous peak flows were predicted to increase by approximately 25 to 30%, with slightly lower increases as flood volume increases. These increases in runoff volume and peak flow were considered to be manageable in terms of erosion and flood risk, and/or infrastructure damage. This level of wetland area retention likely reflects the average "current" wetland area retention in the Assiniboine, Qu'Appelle and Souris river basins, which is overestimated in this study (see reasons below).
- 50% wetland area retention was predicted to increase runoff volumes by approximately 100 to 110% for events with 1:2 year return periods, 35 to 40% for events with 1:10 year return periods, and 10 or 11% for events with 1:100 year return periods. Instantaneous peak

> flows were predicted to increase by approximately 65 to 75%, with slightly lower increases as flood volume increases. These increases in runoff volume and peak flow were considered to present significant erosion and flood risks and potentially damage existing infrastructure. A wetland mitigation policy target of 50% retention of historical wetland areas could present serious challenges for the province without additional requirements to reduce runoff volumes and peak flows.

Throughout this report, “current” estimates of wetland area retention often exceed 80%, which contradicts several previously published estimates of wetland loss in the Prairies. The overestimation of “current” wetland area retention in this study is likely due to an assumption that “farmed” wetlands and 50% of the area of “partially-drained” wetlands were included in the calculation of the “current” wetland area. The calculation of “current” wetland areas only impacts the “current” wetland retention scenario. All other wetland retention scenarios presented in this report are for 10% decrements from the “historical” wetland area.

The CDA method was found to be insufficient for predicting the impact of wetland retention scenarios in the northeast region of the province. In this region, the ratio of effective to gross drainage areas (CDA ratio) is high (> 0.6), so the CDA method underestimates increases in EDA, which are used to predict changes in runoff volume and peak flow rates. The CDA method does not account for the impacts of wetland drainage when it occurs in the historically defined EDA, nor does it consider the efficiencies of runoff transportation to streamflow when channel improvements are made within the EDA. Importantly, wetland area retention is the lowest in this region of the province, so the actual impact of wetland drainage on runoff volumes and peak flows could be quite high. More research and/or modelling work is needed to better understand wetland drainage impacts in this region. Additional policy options, beyond simply choosing a percentage-point wetland retention target, were considered in this project. These were: 1) wetland size exclusions and 2) flow controls.

Allowing wetland size class exclusions from potential wetland policy scenarios was found to have the following impact:
Excluding wetlands less than 0.5 acres in size (Class 1 and 2) from a wetland policy could reduce the wetland area retained in Saskatchewan by up to 20% more than the intended policy level (i.e., a policy that states “retain 80% of historical wetland area, excluding Class 1 and 2 wetlands”, could result in 60% retention of historical wetland area). Excluding wetlands less than 5 acres in size (i.e., keep all Class 5 wetlands and allow the rest to be drained) could result in only 40% retention of historical wetland area in Saskatchewan.

Throughout this report, wetland sizes are used as a proxy for wetland permanence classes based on information provided by the Water Security Agency. It is important to note that wetland size is not synonymous with wetland class. Wetland size was used as a proxy for the wetland permanence class in this analysis because the wetland permanence class is not provided in the CWI dataset. Further examination of existing data may provide better approximations of the impact of wetland size or permanence class exclusions on prairie hydrology as part of wetland mitigation policy development.
Using flow controls (i.e., small culverts to reduce flows) as a beneficial management practice (BMP) to reduce the impact of increased peak flows caused by drainage projects was found to:
Decrease peak flows for high frequency, low volume events in small drainage project areas and should continue to be used at the network scale to reduce peak flows. However, erosion risk can remain high at the outlet of flow controls, so extra erosion control measures should be included in the drainage project design. Finally, wetland policy decisions require an evaluation of trade-offs. The results presented in this

report should be considered in concert with the results of the reports by Dwight Williamson (Water Quality Specialist) and Bob Clark (Wildlife Habitat Specialist) and should also consider social and economic trade-offs within Saskatchewan and in neighbouring jurisdictions. The results presented in this report also do not include the potential impacts of future climate change. This is an important limitation of this work and a topic that should be considered as part of Saskatchewan's wetland mitigation policy development.

2. Water Quality – Dwight Williamson

The goal of this project was to identify the likely water quality impacts reasonably expected from various wetland drainage and retention scenarios within Saskatchewan. The analyses covered nearly 15,000 km^2 of wetlands within a watershed area of over 150,000 km^2.

Wetlands are landscape features formed by the periodic or permanent presence of ponded water in shallow depressions, are characterized by hydric soils, and have aquatic vegetation adapted to growing in shallow water or in wet or moist environments. While wetlands are permanent and stable features on the landscape unless drained or filled, the presence and amount of ponded water varies from season-to-season and from year-to-year with some ponds being ephemeral, holding water only for a few weeks at a time, while others are more permanent.

Wetlands provide many water quality benefits not replicated elsewhere on the landscape including reducing nutrient, salt, and sediment contributions to downstream systems. Wetlands also provide significant water-related resilience in a changing climate. Conversely, wetlands reduce the amount of land that may be placed under agricultural production thus impacting financial returns, requiring time-consuming inconvenience to circumvent with modern, large-scale equipment, and resulting in costly duplication of tillage and inputs due to application overlap.

The extent of drainage in Canada since agricultural expansion began in the late 1800s is uncertain, but estimates (usually based on numbers of wetlands) range up to 70 % in some areas, with about 30 % loss of wetlands in the Prairie Pothole Region. On average, the analyses conducted on artificial drainage of the inventoried wetlands in Saskatchewan's agricultural region and discussed in this report, indicates that wetlands historically covered an area of about 14,693.61[1] km^2. In this analysis, about 7.5 % (or potentially up to 11.2 %) of the historical areal extent of wetlands in the inventoried regions of Saskatchewan have been lost, with considerable variability of drainage and retention from one sub-subbasin to another[2].

Field studies in Saskatchewan, in other Canadian prairie watersheds, elsewhere in North America, and at other sites around the world have shown that artificial wetland drainage can contribute sediment, nutrients, and various salts to aquatic systems. In many cases, the impacts to water quality are subtle and may be difficult to measure, especially when drainage includes one small wetland at a

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[1] Throughout, values are often reported with up to four decimal places, consistent with how that value may have been presented in an accompanying table. In all cases, these resulted from multi-layered calculations where it was not practical or possible to report significant figures. It is recognized that this implies a higher level of accuracy than almost certainly exists but was done to report calculated values in a consistent manner.
[2] The 7.5 % current areal extent of wetland loss estimated in this study is likely an underestimate, as suggested by subsequent hydrological assessment, based upon how "farmed" and "partly drained" wetlands were handled in the analyses.

time. However, when artificial drainage is expanded to include a larger area of wetlands within the same watershed, water quality impacts can become more obvious, measurable, and significant.

Of the water quality concerns related to wetland drainage, the contribution of nitrogen and phosphorus to downstream waters is the most significant concern. In most cases, contributions of salt (*e.g.* Na, Cl, K, SO_4, etc.) following drainage will not present a water quality issue, except locally when drainage occurs from wetlands with high salt concentrations. This occurs mainly with wetlands overlying glacial sediments high in sulfate and that have been hydrologically isolated for long periods (that is, within closed basins). Saline wetlands occur throughout southern Saskatchewan and include those in the Chaplin Lake region, the Quill Lakes area, plus others.

Additional drainage of wetlands will increase nitrogen and phosphorus contributions to downstream waters and exacerbate already existing eutrophic conditions. Phosphorus and nitrogen are essential nutrients and in correct amounts, yield healthy, productive aquatic ecosystems. In excessive amounts, nitrogen and phosphorus can fuel significant and harmful algal blooms including cyanophytes or blue-green algae, some species of which can produce toxins, or may promote species of algae within a lake-wide community that are less preferred as food sources by resident fish species. Significant blooms interfere with the use of water systems for recreation, drinking water, and livestock. When blooms decay, they can cause anoxia, leading to fish kills. There is a complicated relationship between sufficient N and P to promote a healthy, productive fishery and insufficient or excessive amounts that diminish the productivity and harvestability of the fish community.

Eutrophication caused by the enrichment of surface waters by phosphorus and nitrogen is a significant issue in Saskatchewan, as it is elsewhere in the prairie region, throughout Canada and indeed, throughout the world. It has been identified as well, as a significant issue in most Saskatchewan Watershed Plans, prepared by local watershed advisory and technical committees.

Saskatchewan, along with downstream jurisdictions that share Saskatchewan's watersheds, all have in place water quality objectives[3] to protect important water uses including the protection of aquatic life and its habitat, water used for drinking purposes, livestock watering, irrigation, and aquatic-based recreation. Most of the objectives in place include water quality constituents that can be affected by wetland drainage and retention and many specifically reference eutrophication.

Various wetland drainage and retention scenarios were analyzed in this project. Wetlands were initially modelled as if restored to their initial historical areal extent, then impacts were predicted as wetlands were drained in 10 % decrements by area to ultimately include all wetlands except those on protected lands, those on soils unfeasible or not possible to be farmed, and those small wetlands that can be farmed without being drained. Thus, the starting point for estimating water quality impacts from wetland loss scenarios began with the historical wetland areal extent and not the current areal extent. During the analyses, the principal focus was on changes in sediment, phosphorus, and nitrogen losses

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[3] Within Saskatchewan and downstream jurisdictions, there are a range of terms used to describe water quality conditions that should not be exceeded to protect a body of water or a specific water use. These include the terms "standards", "objectives", "guidelines", "targets", plus others and in most cases, relate to the site-specific nature of the condition or to the use to which the condition is intended to be used. For example, "standards" are enshrined in a jurisdiction's legislation and may be legally binding, while a "target" would imply a goal to work towards through best efforts. As applicable in the following report, these are presented as defined in the source publications except where a generalized term is appropriate in which case, "objectives" is used.

from the landscape and contributed to the aquatic environment arising from each of the wetland drainage and retention scenarios.

This process was run for Saskatchewan's wetland inventory in nine river basins and their 58 sub-subbasins. In addition, five case-studies were conducted where potential impacts were assessed in more detail. The five case studies included assessing potential impacts to a small prairie stream in eastern Saskatchewan (the Assiniboine River at Kamsack), a small reservoir in southeastern Saskatchewan (Moosomin Lake), a large reservoir supplying drinking water to about 25 % of Saskatchewan's population (Buffalo Pound Lake), the chain of eutrophic lakes along the Lower Qu'Appelle River (Pasqua, Echo, Mission, and Katepwa lakes), and finally, Saskatchewan-related transboundary impacts to Lake Winnipeg, a large lake situated solely in Manitoba but which receives drainage from a shared 1,000,000 km^2 watershed.

The Saskatchewan-wide wetland inventory covered 233,571 quarter sections and a watershed area of 150,737.86 km^2. Historically, within the inventoried region, wetlands covered 14,693.61 km^2 with current wetlands covering 13,591.73 km^2, or 92.50 % of the historical extent. There was considerable variability among basins and among sub-subbasins. There was limited wetland drainage in the Missouri River and North Saskatchewan River basins with current wetlands covering 99.41 % and 98.78 %, respectively, of the historical wetland areas. In contrast, approximately 27.92 % of the wetlands have been drained in Saskatchewan River's sub-subbasin 05KB.

Province-wide, the loading of sediment, TP, and TN to water systems is estimated to be reduced by 12,175.06, 74.38, and 370.10 tonnes/year, respectively, should all 7.50 % of currently drained wetlands (or 1,101.88 km^2) be restored to their historical extent. Drainage of 10 % of the Province's areal extent of wetlands from the historical level would contribute 27,443.16, 99.18, and 493.52 tonnes/year of sediment, TP, and TN, respectively, to aquatic systems. Should all wetlands be drained except those on protected lands, those located on lands unfeasible or not possible to be farmed, and those small wetlands that can be farmed without being drained, 222,421.89, 803.85, and 3,999.93 tonnes/year of sediment, TP, and TN, respectively, was estimated to be loaded to the Province's waterways, an increase of slightly more than 10 times current contributions from drained wetlands.

Analyses of the five case studies yielded additional detail and understanding. Overall, for each drainage and retention 10 % decrement by area of wetland, sediment loading would increase between 3.5 % and 17.9 % beyond existing loading background, TP would increase between 1.3 % and 21.9 % beyond existing loading background, and TN would increase 0.5 % to 15.8 % beyond existing loading background. Restoration of wetlands to their historical extent follows the same pattern, with similar reductions in loading being predicted for each 10 % of wetland area restored. In terms of how the wetland drainage and retention scenarios would affect the degree to which water quality objectives would be exceeded, it appears that the objectives set by the Prairie Provinces Water Board for sediment in the Assiniboine River at Kamsack would begin to be exceeded regularly at a wetland drainage level of 10 to 20 %, TP at a drainage level of 30 to 40 %, and TN, at a drainage level around 10 % or near the current level of drainage. There would be considerable variability from one month to another.

Although there are many sources of nitrogen and phosphorus entering the Province's waterways including runoff from the naturally nutrient-rich soils of the Canadian prairies which, in some cases such as the Qu'Appelle system, historically have been eutrophic, modern-day agriculture is a significant anthropogenic contributor of nutrients to aquatic systems. Further wetland drainage without equivalent offsetting mitigation, either within the agricultural sector or within broader society including urban areas, will continue to add nutrients to the Province's aquatic systems, in many cases, exacerbating existing water quality issues or creating such issues where none now exist. Within this report, a review is also provided of Beneficial Management Practices that may provide offsets or mitigate additional wetland drainage.

It can reasonably be argued that the threshold for water quality impairment arising from wetland drainage has already been reached or exceeded, not necessarily solely due to impacts from current wetland drainage, but because of the incremental changes that would occur from additional wetland drainage when added to what society has already contributed from many other sources. Saskatchewan, similar to many jurisdictions including those within the Canadian prairie region, has put in place costly measures to reduce the contribution especially of nitrogen and phosphorus to aquatic systems and to place strict control measures on new sources. Nutrient contributions from additional wetland drainage without offsetting mitigation may threaten the success of these existing expenditures and initiatives. Moreover, many of the recent excellent studies assessing Beneficial Management Practices on prairie agricultural lands did so not as offsets to additional contemplated future contributions from wetland drainage, but as viable options to reduce current contributions, which are already too high, and instead, to keep valuable nutrients on the productive landscape to benefit growing crops.

One of the goals of this wetland drainage and retention scenario project was to provide information to assist in identifying thresholds beyond which further drainage should not occur or if further drainage is contemplated, what mitigation measures should be implemented. While this question should be guided by science, it is also a policy matter for the government of Saskatchewan since it involves trading-off benefits derived from economic development, sometimes accruing in one sector, with costs including environmental costs, sometimes being borne elsewhere. It is noted as well, that in Canada, there is a complex inter-jurisdictional Constitutional, legal, and co-operative arrangement concerning responsibilities for water and for resources supported by water involving Provincial, Federal, and Indigenous peoples' governments. The findings of the water quality component of the wetland drainage and retention project may assist with the science-based input to Saskatchewan's policy decisions on wetland drainage and retention including related inter-jurisdictional matters.

3. Wildlife Considerations – Robert Clark

Saskatchewan's Water Security Agency (WSA) is developing a new wetland mitigation policy to support environmentally responsible agricultural development.
To achieve this goal, WSA is conducting multi-faceted evaluations of the costs and benefits associated with wide-ranging wetland retention scenarios. This report focuses on wildlife habitat.
A qualitative review of relationships between wetland and adjacent riparian habitat and wildlife populations indicated that accelerated wetland losses to drainage for cropland expansion:

- could reduce white-tailed deer and moose populations, with possible adverse impacts on hunting opportunities;
- would have negative effects on critical habitat and populations of several priority wetland bird and amphibian species, while
- populations of beneficial invertebrates (e.g., pollinators, pest predators) inhabiting

wetland margins could also be negatively affected.

A quantitative analysis incorporating wetland inventory and land cover data explored how wildlife habitat, bird abundances, and bird species richness could change in response to reduced levels of wetland retention (ranging from historic, through 10% decrements in wetland area, to the lowest retention levels on lands composed of protected areas and lands with low crop production potential). Modelling results indicated that:
as expected, areas of remaining wildlife habitat declined quickly with progressive wetland reductions as wetland and natural upland habitats were converted to crop production:

- model-predicted wetland-associated bird abundances decreased in direct proportion to wetland retention levels;
- aerial insectivore (birds that capture flying insects) abundance also declined but at slightly slower rates than wetland birds relative to wetland loss.
- there was no clear indication that decreases in bird abundances became stronger or weaker as wetland retention levels declined (i.e., no threshold effects were evident).

Focused case-studies based on wetland inventory and land cover data for the Qu'Appelle River basin showed that:

- average bird species richness decreased gradually as wetland drainage and clearing of natural land cover progressed;
- preferentially draining smaller wetlands (e.g., Class III seasonal ponds) produced stronger decreases in wetland bird abundances especially during early phases of wetland loss (i.e., threshold effects were evident when wetland drainage was focused on seasonally-flooded ponds). The predicted changes in wetland bird abundances associated with distinct wetland retention scenarios used in these analyses were consistent with expected patterns based on published reports for similar and other species in the Canadian and US prairies.

A review of the relationships between wetland retention scenarios and major environmental policies and agreements indicated that **removing wetlands to expand area of agricultural crop production is directly *contra*** a number of general and specific goals stated in:

- Saskatchewan's Growth Plan, as well as Saskatchewan's Game Management, Climate Change, and Protected Areas Plans;
- North American Waterfowl Management Plan and North American Bird Conservation Initiative;
- Canada's Species at Risk Act; and the
- International Convention on Biological Diversity.

Losses of wetlands and other natural habitats to expand agricultural crop production represent some of the greatest environmental threats to biological diversity – for game and nongame species alike - in Saskatchewan and world-wide.

Wetlands cannot be replaced by upland habitat due to the distinct functions of aquatic systems; whether wetland drainage impacts could possibly be partly mitigated by restoration of upland habitat is largely unknown.

Extensive losses of smaller wetlands such as seasonally-flooded Class III wetlands would be nearly catastrophic for Saskatchewan's wildlife; these Class III wetlands – as well as complexes of wetlands composed of varying size and permanence classes - must be conserved to safe-guard the large number of species that rely on these highly productive, unique systems.

4. Groundwater Considerations - Garth van der Kamp and David Milo Ferris

Available data on the impacts on groundwater levels of wetland drainage in southern Saskatchewan are limited and insufficient for identification of discernible effects on groundwater levels of regionally important aquifers and available groundwater supplies.
The net aquifer-wide impact on groundwater of wetland drainage coupled with the removal of perennial wetland vegetation is uncertain, has not been quantified through field studies, and may be small. Impacts of wetland drainage on groundwater resource availability should be evaluated for individual projects on the basis of landforms and hydrogeological settings.

In the prairie region of Saskatchewan most groundwater recharge occurs by infiltration beneath ponds in small depressions and wetlands where water collects during snowmelt and heavy rains. There is a concern that if wetlands are drained so that surface water is not ponded in them, then recharge of groundwater beneath the wetlands may be reduced and groundwater resource availability may be diminished. This concern can be addressed from the point of view of whether wetland drainage causes changes of the groundwater levels, which in turn are a direct measure of changes in groundwater availability: if the background groundwater level around a well declines then the sustainable pumping rate of the well is reduced.

Potential impacts of wetland drainage on groundwater resources were assessed through a review of published literature on groundwater recharge and discharge processes in the prairie region, together with a review of long-term records of groundwater levels for Saskatchewan. There have been numerous field studies of groundwater recharge and discharge in and around intact wetlands. These have shown that within wetlands and their margins there are complex interactions between surface and groundwater, summed up by the concept of "depression-focused groundwater recharge and discharge". However, no published field studies of the impact of wetland drainage on groundwater resources have been carried out in the prairie region.

Groundwater observation wells have been operated in southern Saskatchewan since the 1960's and thus provide valuable information on the variability and long-trends of groundwater levels. Water-level records for the observation wells were reviewed, together with an inventory of the status of the wetlands in the surrounding areas, excluding the wells that have been affected by groundwater pumping. The groundwater levels in all these wells fluctuate over the seasons and annually and in response to multi-year wet and dry periods. The long-term trend of the groundwater levels has been steady or rising over the last five decades. The effects, if any, of wetland drainage are obscured by the fluctuations due to the variations in snowfall and rainfall.

A critical review of groundwater recharge and discharge processes for different types of prairie landforms was undertaken to obtain a more thorough understanding of the possible impacts of wetland drainage and wetland restoration on groundwater levels. Stable isotope data for groundwater indicate that most groundwater recharge occurs during the snowmelt period in small depressions with ephemeral ponding which may not be classified as wetlands and are usually cultivated. Perennial deep-rooted vegetation in and around intact wetlands is a major focus of shallow groundwater discharge by root uptake, as evidenced by the common occurrence of "willow rings" which depend on shallow groundwater that infiltrates beneath the central pond. The NET recharge to the groundwater beneath a wetland is the small difference between the recharge and the discharge that occur in and near the wetland. Changes of the net recharge result in corresponding changes of the groundwater level in underlying aquifers. The effects of wetland drainage on groundwater availability thus depend on how drainage affects the net recharge.

The common removal of perennial vegetation when a wetland is drained reduces groundwater discharge by root uptake, thus counteracting the decrease of groundwater infiltration due to drainage of the ponded water. During snowmelt drained wetland depressions usually hold ephemeral ponds that recharge the groundwater. Drainage ditches also hold water while there is flow through them and thus act as additional sources of groundwater recharge. The change of net recharge due to drainage is uncertain and may be small.

Mitigations of wetland drainage effects on net groundwater recharge would likely involve temporarily retaining water on the landscape after snowmelt. Wetland drainage may reduce groundwater levels in underlying aquifers if pre-drainage infiltration beneath the ponded water is high and discharge by wetland vegetation root uptake is low, as is most likely to be the case for shallow aquifers with groundwater levels that are deep below the ground surface of the overlying wetlands. In all cases of mitigation measures the landforms and hydrogeological setting of a drainage project should be considered, with reference to recharge and discharge processes.

Wetland hydrologic systems are closely connected to groundwater resources. The overall impact of wetland drainage on regional groundwater resources is uncertain but probably small. Increased monitoring and further study of wetland drainage or restoration for high-priority aquifers is recommended, aimed at identifying possible impacts and developing effective mitigation measures if and where these are deemed to be advisable.

Review of the Reports

The reports were reviewed by:
Brian Abrahamson
Ken Belcher, University of Saskatchewan
Eric-Lorne Blais
Masaki Hayashi, University of Calgary
Tim Sopuck
Colin Whitfield

Changes were made to the reports and comments addressed. The list of response to the reviewers comments are in the Appendix to this report in the order that that main reports are listed.

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Appendix - Responses to Reviewers