7.0 CONCLUSIONS AND RECOMMENDATIONS

The 2005 RAMP monitoring program results have been discussed in detail, both from a watershed (Section 5) and regional (Section 6) perspective. The following section provides a brief summary of overall conclusions specific to each monitoring component of RAMP, followed by general comments and recommendations for consideration by the RAMP Technical Program Committee and the RAMP Steering Committee.

7.1 CONCLUSIONS

7.1.1 Climate and Hydrology Component

The outlet of each major river basin in the oil sands region is monitored by either RAMP or the WSC, providing a good basis for assessing potential impacts of oil sands development. Minor weaknesses in the network include:

- The location of station S15 (Tar River near the Mouth) which is actually located some distance upstream of the mouth and therefore does not measure all of the impacts in the Tar River watershed; and
- Lack of winter monitoring on the Tar River and Steepbank River.

Changes in measurement endpoints were strongly dominated by changes in land use such as clearing and drainage, and changes in catchment area due to hydrologic isolation. Withdrawals and releases had relatively less influence on the endpoints, except in the Athabasca River.

Measuring land use changes using satellite imagery, as was done for 2005, was a relatively simple process and provided useful results.

The effect of clearing and drainage was assessed using a very simple approach that assumed a constant percentage increase in runoff throughout the year. The actual effect of clearing and drainage is more complex, and low flows in particular are not well estimated using this simple approach. However, although the analytical approach used for the hydrologic data includes a number of simplifications, assumptions and unknowns, it does provide a useful indication of the potential magnitudes of changes in measurement endpoints. A more detailed and rigorous assessment could be made using the same analytical approach supported by hydrologic modeling, particularly if the model was calibrated using a watershed that was largely cleared.

7.1.2 Water and Sediment Quality Component

Various measurement endpoints were used to assess the potential influence of oil sands development on watershed-specific and regional water and sediment quality. When sediment and water quality endpoints were compared to a regional reference database developed using the RAMP data, the distribution of results relative to the reference median was similar regardless of whether stations/year combinations were designated as *potentially influenced-oil sands* or *reference*. 2005 results indicate that, overall, there is little evidence indicating effects related to ongoing oil sands development on water quality and sediment quality measured by RAMP.

Generally, higher nutrient concentrations were observed in several tributaries to the Athabasca River in 2005, relative to previous years, including the Clearwater, Christina and Firebag Rivers. This trend was observed in areas designated as *potentially influenced-oil sands* and as *reference*.

High concentrations of dissolved solids and various ions were measured in Stanley Creek in the Muskeg River watershed, in fall 2005, which were outside the defined the range of natural variability (i.e., 95% of regional reference observations). Water quality in this creek likely was affected by release of Aurora North's Clean Water Discharge to this creek throughout 2005. This effect also was observed in 2003, when Aurora North first began releasing site drainage water to Stanley Creek via this discharge point, but was not observed by RAMP in 2004, given this discharge was not operational during most of 2004. Water quality in the Muskeg River mainstem was not measurably affected by changes in water quality in Stanley Creek, given water quality measurement endpoints at downstream stations were within historical ranges.

Concentrations of various metals and ions, particularly sulphate, were higher in Isadore's Lake, near the Albian Sands Muskeg River Mine, than in previous years, with sulphate concentrations over 100 mg/L observed in this lake for the first time. Similarly, a significant upward trend in boron concentrations was observed in Shipyard Lake (near the Suncor Steepbank Mine). This trend was significant in water samples collected from this lake in both fall and summer from 1997 to 2005.

Assessment of seasonal variability and water quality in the RAMP water quality dataset from 1997 to 2005 revealed that most water quality observations that exceeded relevant guidelines for the protection of aquatic life were consistent across seasons, and that most (e.g., total aluminum, total iron, total phosphorus) were related to particulate metals in suspended materials that would not generally be bio-available. Generally, high concentrations of these water quality variables were most common in spring and summer, times of high river flows carrying largest amounts of suspended materials. An exception to this general observation is dissolved oxygen, which was observed to be below relevant guidelines in winter at some tributary stations. Generally, results of the seasonal analysis confirmed the value of baseline seasonal sampling within watersheds, as well as confirming that fall is an appropriate season for focused assessment of water quality.

Following guidance from the RAMP Technical Program Committee, methods for analysis of chlorophyll *a* in water were refined in 2005, with resulting data compared against previous years. Improved methods in 2005 resulted in a slightly higher frequency of non-detectable values relative to previous years, but did not suggest any relationship between chlorophyll *a* samples in water and other variables known to drive algal production, particularly nutrients.

In the fall 2005 sediment sampling survey, sampling efforts were reallocated from the Athabasca River to the Athabasca River Delta (ARD), given the river mainstem downstream of Fort McMurray is not a truly depositional environment, unlike the ARD, which is the ultimate receiver of suspended sediments from upstream.

Generally, ARD sediments were coarser near its head (i.e., upstream of the Embarras River distributary), and became finer with distance toward Lake Athabasca. Although carbon content generally increased along the ARD toward the lake, hydrocarbon concentrations generally decreased along this gradient. No clear pattern in PAH concentrations were evident among stations sampled, when measured in absolute concentrations or when normalized to carbon or organic carbon content of sediments at each station. Total PAH concentrations at station ATR-ER, in the Athabasca River immediately upstream of the ARD, exhibited an apparent increasing trend from 2000 to 2005, when normalized to total organic carbon (this trend was not apparent in absolute PAH concentration or when PAH was normalized to total carbon rather than total organic carbon). However, various potential confounding factors at this station, particularly related to potential sampling of eroded bank materials and generally high sand content, suggest that this apparent trend may not relate to deposition or accumulation of PAH-containing sediments from upstream sources.

Results of sediment quality monitoring in other tributaries were similar to those of previous years, and did not suggest any trends over time or influences of oil sands operations.

7.1.3 Benthic Invertebrate Communities Component

The strength of the RAMP Benthic Invertebrate Community component is the development of baseline data from multiple watercourses in a baseline condition. Replication within watercourses, and over time, is enabling RAMP the opportunity to extensively characterize the normal range of variability in common metrics of benthic community composition including abundance, richness, diversity, evenness and percent of the fauna such as sensitive mayflies, stoneflies and caddisflies. Rigorous statistical techniques can be used to test for subtle variations in time trends from before to after commencement of operations, or spatially between baseline and operational reaches. Because statistical power is very high, subtle effects that are consistent with operations are inevitable, and were observed with these 2005 data. The regional baseline data, however, typically showed that the significant time trends or spatial variations were subtle in comparison to natural background variability.

Of the river reaches that were considered in an operational condition, benthic communities of the Lower Reach of the Tar River provided the most compelling evidence of effects related to operations. Abundance, richness, diversity and evenness have declined in the Lower Reach since 2003, and those changes were consistent with degrading habitat quality. The absence of mayflies, caddisflies, stoneflies and empidids in 2005 indicated some level of habitat degradation. The Lower Reach of the Tar River is scheduled for re-sampling in 2006, and those data will be useful for confirming the presence/absence of alterations in habitat quality.

Benthic communities from Shipyard Lake (the only lake sampled for benthic invertebrates in 2005 that was designated as *potentially influenced-oil sands*) were dominated by ostracods, and contained numerous midges of the genera *Chironomus* and *Einfeldia*. All three groups are relatively tolerant of degraded conditions, and are indicating an altered habitat quality. All indices of composition of the benthic community from Shipyard Lake, however, were within the expected range of variability as characterized from the two *reference* lakes (Kearl, McClelland), implying that any alterations to habitat quality are minor at most.

Benthos in the Muskeg, Mackay and Steepbank Rivers, and ARD were in good condition relative to natural background conditions characterized from regional baseline reaches.

7.1.4 Fish Population Component

The 2005 RAMP Fish Population component included several core elements in the following oil sands region watersheds:

- Fish inventory - Athabasca River, Clearwater River, Ells River;
- Fish tissue analysis - Athabasca River; and
- Sentinel fish species monitoring - Ells River.

Assessing potential impacts on fish related to oil sands development is an ongoing challenge due to the limited temporal database (many program elements are not conducted on an annual basis) and alterations to the sampling design between years for some elements. These factors make it difficult to establish the level of natural variability associated with impact parameters or measurement endpoints defined for the fish program. Recognizing these limitations, the fish program is continually being refined in terms of establishing standardized protocols and methodologies. As well, non-lethal sampling approaches are being incorporated to allow greater frequency of sampling while minimizing fish mortality. Concluding remarks for each of the three fish program core elements carried out in 2005 are provided below.

Fish Inventory

In 2005, further efforts were made to standardize the analysis of Athabasca River fish inventory data by restricting the calculations of catch-per-unit-effort and composition to fish captured, rather than combining captured and observed fish as in previous years. Standardized current and historical fish inventory data from the Athabasca River indicate some level of species-specific variability in designated measurement endpoints (i.e., relative abundance, length-frequency distribution, size-at-age and condition factor). However, preliminary statistical analysis of the inventory data thus far have demonstrated limited significant differences among years with no clear trends. Additional inventory data gathered in a standardized fashion are needed to allow for appropriate trend analysis. To date, there is little evidence to suggest that characteristics of key indicator fish populations in the Athabasca River have changed during increasing oil sands development in the Athabasca oil sands area.

2005 was the third successive year a fish inventory was conducted on the Clearwater River. The fish community in the Clearwater River appears to be similar to that found in the Athabasca River. The three-year dataset is not adequate for detailed analysis of the designated inventory measurement endpoints (e.g., relative abundance and condition factor). As was the case in the two previous years of the inventory, no lake white fish were captured during the fall sampling. This adds further support to the idea that this species does not use the Clearwater River for spawning or as a migration route, as they do in the Athabasca River.

Species diversity and catch/effort results from the Ells River fish inventory are similar to those generated from the sentinel species monitoring reconnaissance conducted in 2004. Small-bodied fish species, particularly longnose dace dominated the inventory catch. A single year of inventory data is not sufficient to establish natural variability in the fish populations. Additional years of standardized data gathering and analysis are required to establish baseline conditions in this watershed.

Fish Tissue

In 2005, potential effects on human health were assessment from individual and composite fish tissue samples collected from the Athabasca River. None of the 2005 mercury concentrations for lake whitefish exceeded Health Canada consumption guidelines for potential human health risks. In contrast, results for walleye analyzed from the Athabasca River indicate that, due to elevated concentrations of mercury, there is potential risk from human consumption. The potential human health risks from consuming Athabasca River walleye pertain to all fishers, including subsistence, recreational and sensitive subpopulations (i.e., children, pregnant women) based on the 2005 results and those previously documented by RAMP. Other metals and tainting compounds did not appear to pose any human health risks. Although mercury concentrations in Athabasca River walleye tissues exceeded Health Canada and USEPA guidelines, comparison with historical data from the Athabasca and Muskeg rivers, as well as other fish populations illustrates that these concentrations fall within the natural range of concentrations observed in this region of Alberta.

Effects on fish palatability were not predicted by the 2005 data, given that concentrations of all measured tainting compounds were below detection limits and well below screening values.

Sentinel Fish Species Monitoring

The non-lethal sampling methodology, introduced during the 2004 sentinel program on the Athabasca tributaries, was continued for the Ells River sentinel species monitoring in 2005. Based on the results of a reconnaissance survey in 2004 and the 2005 fish inventory, it was determined that longnose dace was the only small-bodied fish species present in sufficient numbers to be used as a sentinel species in the Ells River watershed. Although at present all of the Ells River watershed is designated as *reference*, the primary measurement endpoint for the sentinel program is condition factor. In this regard, condition factor was significantly higher in fish captured at the lower watershed site. Other parameters, such as population distribution were significantly different between watershed sites during both sampling periods (summer and fall). It should be noted that several factors may have influenced the results from this study. These include: the difficulty in capturing sufficient longnose dace, particularly at the lower site during the fall sampling effort; the low number of young-of-the-year at both sites; the fractional spawning behavior of the species; and the documented comparatively slow growth rate of longnose dace, all of which makes the detection of population distribution changes difficult. Further monitoring programs will be needed to establish basic population characteristics of longnose dace in the Ells River watershed.

7.1.5 Acid-Sensitive Lakes Component

As a lake population there have been no significant changes in the chemistry of the 50 RAMP lakes in 2005 compared to previous years.

Using the 95^{th} and 5^{th} percentile as criteria, lakes having unusual chemistry were identified from the 2005 monitoring data. These included three lakes having very low levels of Gran alkalinity (Lakes A21/168, A26/170, and 287), two lakes having very low values of pH (Lakes A21/168, A29/169) and two lakes having the extremely high concentrations of dissolved organic carbon (Lakes A42/165, E15/268). Lakes having the lowest values of Gran alkalinity and pH were found largely in the upland regions (Stony

Mountains and Birch Mountains). Lakes with the highest levels of Gran alkalinity and pH were Lakes 270, 271 and Kearl Lake. These high alkalinity-high pH lakes were found in the region N-E of Fort McMurray.

As in previous years, the RAMP lakes fit into the general range of chemical parameters characteristic of lakes in the region with the following differences:

- The RAMP lakes covered a slightly narrower pH range with a lower median value;
- Titration alkalinity, conductivity, sum of the base cations and principal anions were all less in the 50 RAMP lakes;
- Colour and DOC were significantly greater in the RAMP lakes; and
- Nitrate concentrations were significantly greater in the RAMP lakes.

Piper plots of the 2005 data indicated that most of the RAMP lakes were of the Ca-Mg-bicarbonate type with 8 lakes having 40% or more of the anion charge attributable to sulphate and chloride rather than bicarbonates/carbonates. These 8 lakes were all poorly buffered, low pH lakes in the Stony Mountains and Birch Mountain upland regions.

Dissolved and total trace metals were examined for the first time in the RAMP lakes. In general, most trace metals were quite low in concentration and many were less than detection limits. While extreme values, identified as greater than the 95th percentile concentration, are scattered across the 50 lakes, the lakes having the highest metal concentrations (aluminum, arsenic, cobalt chromium, copper, iron, lithium nickel, lead antimony, thorium, titanium, vanadium and zinc) were found in the Birch Mountains. These lakes were all soft-water lakes with relatively low pH, low conductivity and low acid neutralizing capacity. The high metal concentrations in these lakes are considered to be natural in origin rather than the result of emissions from regional industry.

Exceedances of Alberta and CCME Surface Water Quality Guidelines for Protection of Aquatic Life were observed for aluminum, cadmium, iron and mercury. The guideline exceedances are scattered throughout the various sub-regions with a large representation from lakes in the Birch Mountains and the Stony Mountains regions, consistent with the high metal concentrations found in lakes from these two regions. These exceedances are also considered to be natural occurrences.

Critical Loads were calculated using the Henriksen Critical Load model modified to account for the contributions of both strong and weak organic acids. Critical Loads in 2005 ranged from -0.132 keq H^+/ha/y to 2.008 keq H^+/ha/y with an average value of 0.419 keq H^+/ha/y. Lakes located in the upland regions (the Birch Mountains, the Caribou Mountains and the Stony Mountains) and in the Canadian Shield had the lowest Critical Loads and were the most acid-sensitive by this criterion.

The Critical Loads of acidity were compared to modeled rates of acid deposition for each lake published in the Kearl Lake EIA (potential development case). The rate of Critical Load exceedance in 2005 was 35.4 % (17 of 48 lakes). This rate of exceedance was considerably higher than the rate of 8% reported for 399 oil sands lakes in a recent lake sensitivity report to the NO_xSO_x Management Working Group using the same model modifications (WRS 2006). The higher rate of exceedance in the RAMP lakes reflects a bias in the RAMP monitoring program where the most poorly buffered lakes were preferentially selected for study. The rate of Critical Load exceedance in the RAMP lakes is similar to rates observed in four sensitive regions in Ontario. A large number of the exceeded lakes (10 of the 17 lakes in 2005) would have been exceeded under background levels of deposition. Critical Load exceedances do not necessarily mean that acidification of a lake is imminent.

Estimates of seasonal variability in Gran alkalinity, pH, base cations, sulphate, DOC and nitrates were reported for the first time on 10 RAMP lakes from data supplied by Alberta Environment. The data showed very significant seasonal fluctuations in most parameters. These large fluctuations suggest that greater standardization is required regarding the appropriate time to sample the study lakes.

Mann-Kendall trend analysis was applied to key measurement endpoints to detect trends that might indicate incipient acidification of the RAMP lakes. Analytical error and the information on seasonal variability in these parameters were incorporated in the interpretation of the trend analysis. As most of the trends were inconsistent and often illogical, there was no evidence to suggest that there have been any significant changes in lake chemistry over the length of the RAMP program. The high seasonal variability in these parameters renders the task of detecting minor year-to-year changes extremely difficult.

7.2 RECOMMENDATIONS

From a sampling design and technical point of view, the three primary objectives of RAMP are:

- To monitor aquatic environment in the oil sands area to detect and assess cumulative effects and regional trends;
- To collect baseline data to characterize variability in the oil sands area; and
- To collect and compare data against which predictions contained in environmental impact assessments (EIAs) can be assessed.

The recommendations listed below, by RAMP component, are presented for consideration for continued, ongoing strengthening of the program.

7.2.1 Climate and Hydrology Component

- Consider additional monitoring at locations upstream of development, possibly including reactivating Station S4, Blackfly Creek near the Mouth.
- Consider installing fencing around those stations which have been most prone to damage. Rainfall and snowfall monitoring stations, in particular, (except for C1, the Aurora Climate Station, which is fenced) have frequently experienced periods of missing data due to damage from wildlife.
- Data quality at Station S18A, Calumet River Upland Tributary, was affected by a large beaver dam downstream of the station in 2005. Consider moving the station or removing the beaver dam.

- Develop and regularly update an overall plan of the oil sands area north of Fort McMurray, showing anticipated progress of mining development and reclamation. The map would be used for planning changes to the climate and hydrologic monitoring network.

- Continue quantification of areas of land change using satellite imagery. Higher resolution imagery would facilitate identification of specific drainages and land uses.

7.2.2 Water Quality Component

- Given the high incidence of non-detectable observations of chlorophyll *a*, the lack of any correlation between chlorophyll *a* and related water quality measures (i.e., nutrients), other potential confounding factors affecting suspended chlorophyll concentrations in flowing waters, and that periphyton already is measured within various regional tributaries by the RAMP Benthic Invertebrate Community component, the measurement of chlorophyll *a* in waters, particularly rivers, by RAMP likely does not provide useful or meaningful monitoring data to the program.

- Continue to focus RAMP water quality sampling in fall, as it is broadly representative of water quality observed in other seasons, but also continue to measure seasonal water quality at newly established stations, per the existing RAMP water quality design.

7.2.3 Sediment Quality Component

- Continue to focus Athabasca River sediment monitoring on the ARD, and not along the non-depositional river mainstem upstream of the delta, with monitoring conducted at least as frequently, and at the same locations, as is done for the Benthic Invertebrate Community component.

- As outlined in the recent RAMP Design and Rationale document (RAMP 2005b), consider redesigning the RAMP Sediment Quality component to focus on depositional areas only, through harmonizing the component with depositional areas sampled by the Benthic Invertebrate Community component, and eliminating sediment sampling in erosional river reaches that are currently sampled by RAMP.

7.2.4 Benthic Invertebrate Community Component

- During future benthic surveys, it is recommended that RAMP quantify landscape features that naturally influence the condition of benthic invertebrate communities. This information will allow RAMP to develop regional reference models based on the underlying landscape features and will further improve the assessment of benthic communities in areas designated as *potentially influenced-oil sands*.

7.2.5 Fish Population Component

- Currently, all inventory fish sampling areas on the Athabasca River have been designated as *potentially influenced-oil sands*. In order to enhance the monitoring function of the inventory program it may be appropriate to include a *reference* area as part of the sampling regime. The *reference* area should be located in a reach of the Athabasca River that is situated upstream from oil sands development and has comparable habitat features.

- The non-lethal approach to sentinel species monitoring should be continued in the Athabasca River tributaries. Currently, condition factor is the only measurement endpoint that has an assigned impact criterion. Implementation of further non-lethal sentinel species programs under RAMP will help to provide the basis for formulation of impact criteria for other proposed measurement endpoints associated with fish growth, survival and reproduction.

- Non-lethal sentinel species monitoring should be expanded to include the Athabasca River using trout-perch as the sentinel species. Appropriate sampling strategies that consider life history characteristics of trout-perch and information requirements for the non-lethal approach must be developed prior to implementation.

- Continued efforts are needed to standardize field data collection procedures/methods and data analysis for the fish inventory program, particularly on the Athabasca River.

- Development of a non-lethal biopsy sampling approach for the RAMP fish tissue program has proceeded well based on results from pilot studies conducted in 2004 and 2005. Efforts should be made to further expand and refine the non-lethal approach to tissue collection.

7.2.6 Acid-Sensitive Lakes Component

- The high degree of seasonal variability observed in key measurement endpoints strongly suggests that sampling times and the frequencies of sampling the RAMP lakes be re-examined in order to detect any potential changes in lake chemistry.

- In order to track the origin and fate of sulphate (the principal source of acidification) in the RAMP lakes, it is recommended that the RAMP water samples be analyzed for isotopic species of sulphur for comparison with isotopic ratios in the stack gases.

- It is recommended to incorporate the results of the zooplankton data from the RAMP lakes available from Environment Canada. The data would be used to identify zooplankton species assemblages and potential changes in these assemblages indicative of acidification.