01 March, 2011

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EC File No.: 4704 004041
DFO File No.: NU-09-0003
TC File No.: 8200-T-11419.1
NWB File No.: 1BW-DUV-xxxx

Kelli Gillard, B.Sc., P.Ag.
Technical Advisor
Nunavut Impact Review Board
P.O. Box 1360, Cambridge Bay
Nunavut
X0B 0C0

Re: Response to Comments Regarding Public Works and Government Services Canada's "Disposal at Sea of Dredged Sediments, Pangnirtung Fjord" Project Proposal

Dear Ms. Gillard:

AMEC Earth & Environmental, a division of AMEC Americas Limited (AMEC) has been contracted by Public Works and Government Services Canada (PWGSC) to provide responses to comments received by the Nunavut Impact Review Board (NIRB) from Fisheries and Oceans Canada (DFO), Environment Canada (EC), and Transport Canada (TC) regarding the "Disposal at Sea of Dredged Sediments, Pangnirtung Fjord" project proposal.

It is also important to note that some comments (in addition to the ones provided in the NIRB letter) were received by the proponent directly by EC. These additional comments have been included in this letter for your information and file.

All responses to comments provided below will be incorporated into the finalization of the Screening-Level Environmental Assessment for the Disposal at Sea of Dredged Marine Sediments, Pangnirtung Fjord, Pangnirtung, Nunavut document.

<u>Fisheries and Oceans Canada (DFO)</u>

Comment: "Provided that the plans implemented as described DFO has concluded that the proposal is not likely to result in impacts to fish and fish habitat. The proponent will not need to obtain a formal approval from DFO in order to proceed with the proposal".

Response: Noted.

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Environment Canada (EC)

General Comments:

- **All mitigation measures identified by the proponent, and the additional measures suggested herein, should be strictly adhered to in conducting project activities. This will require awareness on the part of the proponents' representatives (including contractors) conducting operations in the field. EC recommends that all field operations staff be made aware of the proponents' commitments to these mitigation measures and provided with appropriate advice/training on how to implement these measures.**

Response: Noted. All mitigation measures will be incorporated into an Environmental Management Plan for the disposal at sea of marine sediments in Pangnirtung Fjord. This EMP will be provided to the selected contractor and strictly adhered to.

- **In Box 17 of the application: The centre point of the disposal site is provided but the expected diameter of the proposed site is not consistent in the EIS document. Section 4.2 indicates that the site is ~110,000 square metres which corresponds to a radius of ~187 m but figure 5.14 suggests the radius would be subsequently greater (~350 m) and the text of section 5.2.2.4.4 indicates a radius of about 250 m. What is the expected diameter of the site and how is it defined?**

Response: As described below in a later comment, the volume to be dredged and disposed has been increased to 156,000 m^3 (place measure) in order to account for a 30% bulking factor. The modelling study has been re-done considering this new volume and is attached for your review and files. Considering that 156,000m^3 of material is to be disposed, it would require 104 loads of 1,500m^3 single barge dumps to complete the proposed project. Assuming a typical day with 2 floods, 2 ebbs and 4 slacks tide periods, and assuming that all the barges would be unloading at the exact same location, a composite footprint was estimated adding 13 spring and 13 neap flood, 13 spring and 13 neap ebb and 52 slack bottom footprint thicknesses. The result (refer to Figure 13 of the attached Pangnirtung Ocean Disposal Study Modeling Report) demonstrates a 500m diameter for the most part, with a maximum height just above 2.5m. The area with an estimated thickness of one millimetre or more extends to a diameter of about 1000m or an area of about 70 hectares (Section 4.0 of the attached Modeling Report).

Since the deposited void ratio considered here was about 1.08 (that is a porosity of about 52%) and that the natural, more compacted, in-situ sediment would eventually have a void ratio of about 0.67 (or a porosity of about 40%), the resulting mount should decrease to a height of about 2m maximum (about 80% of its initial value) after compaction period (with the majority of compaction occurring within a period of 2 to 3 months) (Section 4.0 of the attached Modelling Report).

For Figure 5.14 of the Screening-level Environmental Assessment (revised Figure provided below based on above edits to dredge volume), we believe that you are referring to the grey area vs. the coloured one. As such, the grey areas around the mound of the footprint figure, for all the precedents individual scenarios (Figures 5.9 to 5.13 in the Environmental Assessment document; Figures 8 to 12 in the Modeling Report) represent deposition of less than 0.03mm. Surface areas where the thickness of the deposit exceeds 3mm are estimated to be of the order of 10 hectares for all scenarios considered (refer to table 5.8 in Environmental Assessment, Table 6 in the Modelling Report).

In this later case of Figure 5.14 (as above), all the previous deposits were added together so that the resulting grey area became: <0.03*104 = 3.12mm and this is what was meant above with: "The area with an estimated thickness of one millimetre or more extends to a diameter of 1000m" (extracted from Section 5.2.2.4.4 of the Environmental Assessment, page 41, paragraph 2).

Note that the white areas, just in between the coloured mound and the grey area and extending a bit toward the North East is estimated (based on assumption of individual 2mm deposit) to be equal to about 2.6cm (26mm) and is from the accumulation of the fine deposit of the spring-flood scenario (13x2 = 26mm).

Overall, the area with an estimated thickness of one millimetre or more covers an area of about 70 hectares (refer to Section 4.0, last paragraph of the attached Modeling Report).

- **In Box 37 of the application: As outlined in Schedule 6 of CEPA99, proponents are expected to assess alternatives to disposal at sea and to make all practical efforts to reduce the amount of waste to be disposed at sea. Was waste reduction considered in the design of the project? What reduction opportunities were examined and why were they rejected?**

Response: PWGSC has advised that land-based disposal was originally considered as an option, but was discarded for the following reasons. Due to other construction activities still to take place in the area of the inner harbour during the 2011 construction season, the dredge work has been planned to start from the Fjord and work towards the land. This would mean that the accessibility to the existing harbour would be poor for any disposal scows due to its current reduced width and depth. Also, it is understood that the dredged materials are less than useable (mostly silts). Given these conditions, and the fact that the materials from the inner harbour used to fill in the new sealift landing area would not compact properly, the decision was made to not salvage any of the dredged materials. Compounding the disposal of the dredged materials was the double handling and the lack of heavy civil equipment on site. It is recognized that this may have changed now with the other work that SCH is currently carrying out, but the equipment will be totally committed to that other work and would not be available for handling and disposal of the dredgate.

- **In Section 4.2 of Appendix B: This section indicates that approximately 120 000 cubic metres (place measure) of material is to be dredged/disposed but section 5.2.2.4.1 (bullet 2) indicates that the estimated 120 000 cubic metres of dredged material includes a 30% bulking factor due to entrainment of sea water during dredging. Please clarify how much material is being dredged.**

Response: The correct volume of material being dredged is 120,000 cubic meters, place measure. There is no bulking factor included in this number, and that reference in Section 5.2.2.4.1 is incorrect and will be changed. There is of course another implication. The modeling was done on the mistaken information that the bulking factor was included in the 120,000 figure. This has now been redone and the results are reported elsewhere in this response document.

- **Figure 5.12: The graph entitled "Long Term Concentration Plume evolution" on Figure 5.12 shows the concentration of the plume actually increasing with distance from the dump site. Please clarify if that is the case and, if it is, why it occurs.**

Response: This is a valid comment and indeed may be a little confusing at first sight. The so called 'Long Term Concentration Plume Evolution Graph' is developed from the 'Long Term' output of STFATE; that is, the evolution of the passive diffusion and advection of the plume due to ambient currents. The concentration is calculated as a function of the distance from the (surface) disposal site (as opposed to the 'short-term' graphs that are calculated as a function of time since disposal). During the Neap-Ebb period, the currents are extremely small (order of few cm/s) at the site (as described in the report). However, the barge itself was assumed to move at the same speed and same direction for all the scenarios; that is a speed of 1.8 m/s toward NE. Therefore, for all the scenarios, the plume had an initial momentum toward the NE (before collapsing), and the material generally drifted a little further to the NE from the (surface) dumping point. Because the currents were so small for that particular scenario, the long term plume was then indeed more concentrated away from the site (about 50m) before being advected back at lower concentration toward the site (about 40m), since the ebbing current goes toward the SW. Our graph representing strictly the concentration as a distance from the (initial, at the surface) dumping point, the concentration indeed appears to increase from the disposal site. The same process was acting during Spring-Ebb but, the current being stronger for that scenario, the 'Long-Term' plume(s) were advected well away from the (surface) disposal site (i.e: it passed the point 0,0), so a decreasing concentration results.

- **Section 5.2.2.1 and Section 6.0: The supplied information describes open-water current and tidal regimes which are important in understanding what can be expected during dredging and disposal operations and the temporal bounds for the review of residual effects are currently limited to "2 - 3 months after the last dump". Are currents at the sediment water interface on disposal site expected to change when the fjord is ice covered? Understanding under-ice currents is necessary to assess the impacts of the project and the long term stability of the site.**

Response: The focus of the study was a short-term analysis of disposed materials because long term fate was not considered an issue considering the deep disposal site. However, based on some characteristics of the circulation observed in Pangnirtung Fjord during Summer 2010 it is possible to anticipate how conditions might change under winter ice covered conditions. The Fjord showed a relatively strong estuarine circulation in the summer due to a large fresh water discharge from rivers and glacial melt: the flow out of the fjord in the fresher top layer is sustained by an influx of saltier water in the bottom layer. The strongest bottom currents observed during the summer program resulted from the combination of this influx and the spring tide flood. With the onset of winter, at the same time ice develops, river discharge and glacial melt cease, stratification disappears and the estuarine circulation shuts down. Hence under ice covered conditions, an important contribution to the strong bottom currents is removed. Furthermore, by the time ice cover has developed, the disposal mound is expected to be well, if not completely, consolidated (consolidation expected to happen over a period of 2 to 3 months as stated in the report). With the reduction in bottom current strength due to estuarine circulation shutting off, and with a consolidated mound, the stability of the mound is expected to be no less under ice cover than assessed in the summer just after discharge.

- **Section 6.1.2.2: This section indicates that personnel "should" report and clean up spills. Spill reporting is not an optional activity; the proponent must commit to spill reporting and clean up as noted in NIRB Condition #15 found in Appendix 1 of Appendix A (Regulatory Review of Marine Environmental Assessment in Nunavut).**

Response: Agreed, the text will be modified to reflect this, including the reference you have noted so that there can be no misunderstanding.

- **Section 6.1.2.2: Bullet #8 indicates that an adequate supply of spill clean-up equipment should be maintained "on site" at all times. Given that the operation involves many vessels operating in different areas the proponent should ensure that all vessels have the appropriate equipment available.**

Response: Agreed, the text will be adjusted to read that all vessels under the control of the proponent will have the appropriate equipment available (it should be noted that some vessels involved in the inner harbour work left over from 2010 and to be completed in 2011 may not be under the direct control of PWGSC).

- **Section 9.0: As the NIRB Part 4 Screening of the disposal activity is currently in progress, it is premature to state that "the RAs have concluded that following the application of mitigation, the project is unlikely to result in significant adverse environmental impacts".**

Response: Agreed, this will be inserted into the final document, assuming of course that it will be applicable. We typically consider the first document submission to be a draft. Then we compile all comments (in this case EC, DFO, NIRB) and issue a final DAS Application and EIS Screening report with the incorporation of all comments.

Additional Comments Directly Received by Environment Canada

- **Section 6.2.2 - CEPA99 Schedule 6 requires that disposal at sea activities be carried out with consideration for "other users of the sea" which includes marine traffic such as private and commercial fishing boats and tourist vessels among others - what mitigations will be put in place to allow these "users" access to the harbour while the channel and entrance are being dredged?**

Response: We have indicated in the EIS that the following measures will be implemented to facilitate ongoing vessel traffic during construction (extracts from Sections 6.2.3.2 and 6.2.4.2):

- Normal notices to mariners, as controlled by the Hamlet Office, will be in place.
- Open communication will be maintained between the proponent and local fishers regarding fishing activities.
- The coordination of Project activities with commercial traffic (fuel delivery, sealift, cruise ships) will be undertaken as required.

We will include a fourth measure, one that we routinely include in some other similar instances, to the effect that "the DFO area office will be advised as per the above conditions".

For your information, we have been advised by the Navigable Waters Protection Program (NWPP) that no authorization is required under the *Navigable Waters Protection Act* (NWPA) for the movements of the dredge scows between the dredge site and the proposed disposal site. We have requested a letter to this effect and will forward a copy to you once it is received.

- **Section 6.1.4.2 - Bullet 6 states that transport and disposal of sediment will cease in the presence of migrating whales - Please clarify what constitutes "migrating" in this context. Will operations cease if individual whales are noted in the area? Will the proponent be establishing a buffer area and to ceasing operations if any whales are observed in the area?**

Response: The presence of whales in the fjord is infrequent, and the numbers are small (individual to small pods). Considering the cultural significance and importance of whales as a traditional food, we will recommend that the contractor employ a spotter at all times during the disposal operations and that those disposal activities be halted if one or more whales are observed within a distance of 3 km of the disposal site.

Wildlife and Species at Risk

- **Section 6 (a) of the *Migratory Birds Regulations* states that no one shall disturb or destroy the nests or eggs of migratory birds. Although this disposal at sea project will take place during the migratory bird breeding season, the project does not overlap with any key marine habitat sites identified for migratory birds in Nunavut. The proponent states that dredging and disposal activities may interfere with migratory birds that nest nearby or use the fjord for resting/staging areas. To mitigate these potential effects they propose that concentrations of seabirds, waterfowl, or shorebirds will not be approached and that the contractor will be made aware of the possible presence of migratory birds such as eiders and gulls occurring at the project site and will ensure that work crews and equipment do not approach these species. A recent study by Diemer et al. (2010)[1] recorded relatively high numbers of Iceland or Glaucous Gulls in the Pangnirtung Fjord and smaller numbers of Eider ducks and Northern Fulmar. The proponents should consider halting operations if large concentrations of birds are encountered along the designated navigational channels between the dredging site and the dumping site, and should wait until birds have moved out of the area to resume operations. The project is unlikely to disturb or destroy nests or eggs of migratory birds given that operations are mainly marine-based.**

Response: The Proponent will ensure that all disposal at sea of dredged material work activities are compliant with applicable legislation, with particular reference to the *Migratory Birds Convention Act* and associated Migratory Birds Regulations, such as:

- Except as authorized by the regulations, no person shall, without lawful excuse,

[1] Diemer, K.M., Conroy, M.J., Ferguson, S.H., Hauser, D.D.W., Grgicak-Mannion, A., and Fisk, A.T. 2010. Marine mammal and seabird summer distribution and abundance in the fjords of northeast Cumberland Sound of Baffin Island, Nunavut, Canada. Polar Biol. DOI 10.1007/s00300-010-0857-1.

(a) be in possession of a migratory bird or nest; or
(b) buy, sell, exchange or give a migratory bird or nest or make it the subject of a commercial transaction.

- No person or vessel shall deposit a substance that is harmful to migratory birds, or permit such a substance to be deposited, in waters or an area frequented by migratory birds or in a place from which the substance may enter such waters or such an area; and
- No person or vessel shall deposit a substance or permit a substance to be deposited in any place if the substance, in combination with one or more substances, results in a substance-in waters or an area frequented by migratory birds or in a place from which it may enter such waters or such an area-that is harmful to migratory birds.

As indicated with other mitigative measures listed in the Screening-level Environmental Assessment document to protect wildlife during Project activities, the proponent will ensure that concentrations of concentrations of seabirds, waterfowl, or shorebirds will not be approached. The contractor will be made aware of the possible presence of migratory birds such as eiders and gulls occurring at the Project site and will ensure that work crews and equipment do not approach these species. It is important to note that this includes not approaching large concentrations of seabirds, waterfowl, or shorebirds within the route of the disposal site which falls within established navigational channels.

- **Section 5.1 of the *Migratory Birds Convention Act* prohibits persons from depositing substances harmful to migratory birds in waters or areas frequented by migratory birds or in a place from which the substance may enter such waters or such an area.**

Response: Noted.

- **Marine birds are vulnerable to oil spills and to pollution of their feeding areas. Environment Canada recommends that the proponent consider what steps would be taken to protect wildlife (including marine birds) in the event of a spill. This information could be incorporated into an existing emergency response and/or spill response plan. This could include specific measures to keep wildlife out of a contaminated area, equipment available to do this, what measures would be taken if animals do come in contact with the spill, and when such procedures should be used. Having this information outlined not only benefits wildlife, but also gives clear direction to the field crew on what to do in a spill situation if wildlife is nearby.**

Response: The proponent has produced an EMP for the disposal at sea of dredged sediments within Pangnirtung Fjord. This document supplements the already existing Construction EMP (CEMP) that together outline mitigation measures required to be adhered to in order to prevent and contain possible oil spills. The selected contractor will also be required to produce and implement a comprehensive Spill Contingency Plan in accordance with the Nunavut Department of Environment Spill Contingency Planning and Reporting Regulations. This document will include specific measures to keep wildlife out of a contaminated area, equipment available to do this, measures to be taken if animals do come in contact with the spill, and when such procedures should be used. Copies of this plan must be readily available on site, and all Project personnel must be made familiar with the appropriate response procedures in the event of a spill.

- **The following comments are pursuant to the *Species at Risk Act* (SARA), which came into full effect on June 1, 2004. Section 79 (2) of SARA, states that during an assessment of effects of a project, the adverse effects of the project on listed wildlife species and its critical habitat must be identified, that measures are taken to avoid or lessen those effects, and that the effects need to be monitored. This section applies to all species listed under Schedule 1 of SARA. However, as a matter of best practice, Environment Canada suggests that species on other Schedules of SARA and under consideration for listing on SARA, including those designated at risk by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC), be considered during an environmental assessment in a similar manner. The Table below lists species that may be encountered in the project area that have been assessed by COSEWIC as well as their current listing on Schedules 1-3 of SARA (and designation if different from that of COSEWIC). Project impacts could include species disturbance.**

Terrestrial Species at Risk [1]	**COSEWIC Designation**	**Schedule of SARA**	**Government Organization with Primary Management Responsibility [2]**
Harlequin Duck (Eastern population)	**Special Concern**	**Schedule 1**	**EC**
Peregrine Falcon	**Special Concern (*anatum-tundrius* complex[3])**	**Schedule 3 – Special Concern (*tundrius*)**	**Government of Nunavut**
Polar Bear	**Special Concern**	**Pending**	**Government of Nunavut**
Wolverine (Western population)	**Special Concern**	**Pending**	**Government of Nunavut**

1 The Department of Fisheries and Oceans has responsibility for aquatic species.

2 Environment Canada (EC) has a national role to play in the conservation and recovery of Species at Risk in Canada, as well as responsibility for management of birds described in the Migratory Birds Convention Act (MBCA). Day-to-day management of terrestrial species not covered in the MBCA is the responsibility of the Territorial Government. Populations that exist in National Parks are also managed under the authority of the Parks Canada Agency.

3 The anatum subspecies of Peregrine Falcon is listed on Schedule 1 of SARA as threatened. The anatum and tundruis subspecies of Peregrine Falcon were reassessed by COSEWIC in 2007 and combined into one subpopulation complex. This subpopulation complex was listed by COSEWIC as Special Concern.

Response: Noted. SARA schedules for the polar bear and wolverine will be changed to “pending” and the Special Concern status of the Peregrine Falcon under Schedule 3 of SARA will be added to existing text in Sections 5.2.5.1 and 5.2.5.2, respectively of the final screening-level EA document. The possible project-related effects on the above-noted species were assessed in the document and include disturbance to resident species and habitats and degradation of habitat from the accidental release of contaminants (i.e., petroleum products) and increased turbidity near the disposal site.

- **Section 5.2.5.2 (Pg. 53, paragraph 3) of the Disposal at Sea application states that Harlequin Ducks are unlikely to occur in the Study Area; however Mallory et al. (2008)[2] report that Harlequin Ducks breed on Baffin Island, and although the majority of observations are from the Kimmirut area, Harlequin Ducks have been observed as far north as Clyde River.**

Response: Noted. The text of the Environmental Assessment document will be adjusted to reflect the possible presence of Harlequin Duck within the Study Area.

- **If Species at Risk are encountered or affected, the primary mitigation measure should be avoidance. The proponent should avoid contact with or disturbance to each species, its habitat and/or its residence.**

Response: Noted.

- **Monitoring should be undertaken by the proponent to determine the effectiveness of mitigation and/or identify where further mitigation is required. As a minimum, this monitoring should include recording the locations and dates of any observations of Species at Risk, behaviour or actions taken by the animals when project activities were encountered, and any actions taken by the proponent to avoid contact or disturbance to the species, its habitat, and/or its residence. This information should be submitted to the appropriate regulators and organizations with management responsibility for that species, as requested.**

Response: A suitably qualified and experienced Environmental Monitor (EM) will be employed from the local community (if possible) to ensure all activities are conducted in compliance with applicable legislation. Duties of the EM will include, but are not limited to:

- Ensuring the Contractor and workers are trained on the methods to prevent spills and how to respond in the event of a spill, and that appropriate spill kits and absorbents are on-site and readily accessible.
- Attending daily tailgate meetings to provide support and information to the Contractor regarding ongoing environmental issues and ensuring compliance is occurring.
- Halting disposal activities that are resulting in adverse environmental impacts (i.e., disturbance of species at risk; visual evidence of impact due to mitigation failure, spills, etc.).
- The EM will work with the Contractor to rectify the issue and ensure further mitigation measures are implemented, as appropriate, and will advise the Contractor when activities may be permitted to re-start.

[2] Mallory, M.L., Fontaine, A.J., Akearokl, J.A., Gilchrist, G. 2008. Harlequin Ducks in Nunavut. Waterbirds 31(sp2): 15-18.

- Ensuring any hazardous materials used, stored, and disposed of are in accordance with the information contained in their Material Safety Data Sheets (MSDS).
- Ensuring the Contractor replaces used spill abatement and clean-up materials and maintenance of the inventory throughout the duration of operations.

The EM will also complete and maintain monitoring and auditing documentation for PWGSC's records, on behalf of DFO-SCH. The EM will complete daily reports during each audit which will be summarized with weekly reports and provided at PWGSC's request. Monitoring data and observations from a Designate Monitor (DM) will be included in the weekly reports during the periods the EM is not on-site. Daily reports will include, but not be limited to:

- Commentary on the disposal activities and the work-site from an environmental perspective (i.e., integrity of mitigation measures, turbidity of water, presence of species, etc.).
- Photo-documentation of activities carried out that day, as appropriate.
- Identification of any environmental issues or impacts that arose or occurred and details of specific mitigation measures put in place to address environmental issues and impacts with notable correspondence and completed action items.

In addition to the daily reports, upon completion of the Project, the EM will provide PWGSC with a final post-Project report. This final report shall contain the following information:

- A summary of disposal at sea activities;
- Comments on the disposal at sea activities from an environmental perspective; and
- Identification of any environmental issues and impacts that arose or occurred and details of specific mitigation measures implemented to address the environmental impacts.

- **For species primarily managed by the Territorial Government, the Territorial Government should be consulted to identify other appropriate mitigation and/or monitoring measures to minimize effects to these species from the project.**

Response: Noted.

- **Mitigation and monitoring measures must be taken in a way that is consistent with applicable recovery strategies and action/management plans.**

Response: Noted.

- **Harlequin Ducks spend most of the year in coastal marine environments, but they move inland each spring to breed along fast-flowing turbulent streams. Their nests are usually built on the ground along the stream banks. Harlequin Ducks are tolerant of moderate levels of disturbance, but they will abandon a site when the disturbance becomes chronic. Disturbance events can include boating and chronic human presence. If a Harlequin Duck nest or a hen with ducklings is encountered, the proponent should avoid activities in the area until nesting is complete and the brood has moved beyond the range of disturbance.**

Response: Project-related mitigation measures will be amended to include the avoidance of activities in the area where a Harlequin Duck nest or a hen with ducklings is encountered until nesting is complete and the brood has moved beyond the range of disturbance. A photo of the Harlequin Duck will be provided in the EMP to ensure that contractors are familiar with the appearance of this species.

- **Observations of Harlequin Ducks should be reported to the Canadian Wildlife Service of Environment Canada through the NWT/NU Bird Checklist Program.**

  NWT/NU Bird Checklist Survey
  Canadian Wildlife Service, Environment Canada
  5019 – 52 Street, 4th Floor
  P.O. Box 2310
  Yellowknife NT, X1A 2P7
  Phone: 867.669.4773
  Email: NWTChecklist@ec.gc.ca

Response: Observations of Harlequin Ducks will be reported to the Canadian Wildlife Service of Environment Canada through the NWT/NU Bird Checklist Program.

- **Implementation of mitigation measures may help to reduce or eliminate some effects of the project on migratory birds and Species at Risk, but will not necessarily ensure that the proponent remains in compliance with the Migratory Birds Convention Act, Migratory Birds Regulations, and the Species at Risk Act. The proponent must ensure they remain in compliance during all phases and in all undertakings related to the project.**

Response: Noted. The proponent will ensure that all Project-related mitigation measures will be strictly adhered to during all phases and in all undertakings related to the Project.

Transport Canada (TC)

Comment: Transport Canada's NWPP will need to be contacted directly regarding the dredging and disposal at sea of marine sediments in Pangnirtung, Nunavut. Please reference the TC file number 8200-09-10626.

As noted above, we have been advised by the NWPP that no authorization is required under the *Navigable Waters Protection Act* (NWPA) for the movements of the dredge scows between the dredge site and the proposed disposal site. We have requested a letter to this effect and will forward a copy to you once it is received.

CLOSING

We trust that these responses satisfy provided comments regarding the proposed Disposal at Sea of Dredged Sediments, Pangnirtung Fjord project proposal. Please do not hesitate to call if you have any questions regarding this, or any other matter.

Yours very truly,
AMEC Earth & Environmental

Fred Meth, B.Sc., M.Sc.
Project Manager

cc Mr. Alan Cadenhead, A/Regional Manager, Navigable Waters Protection Program, Prairie and Northern Region Region, Transport Canada
Ms. Georgina Williston, Habitat Management Biologist, Eastern Arctic Area, Central & Arctic Region, Fisheries and Oceans Canada
Mr. Mark Dahl, Ocean Disposal Specialist, Environmental Protection Operations Directorate, Environment Canada

ATTACHMENT A
Pangnirtung Ocean Disposal Study
Modeling Report

Pangnirtung Ocean Disposal Study
Pangnirtung (Nunavut)

Submitted to:

Public Works and Government Services Canada
Winnipeg, Manitoba

Submitted by:

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February 2011

Project TV01050

DATE	PROJECT NUMBER	REVISION	PREPARED BY	REVIEWED BY
November 2010	TV01050	DRAFT	Sebastien Donnet	Patrick Roussel
February 2011	TV01050	FINAL	Sebastien Donnet	Patrick Roussel

DISCLAIMER

In conducting this study and preparing this report, AMEC Earth & Environmental has applied due diligence commensurate with normal scientific undertaking of a similar nature. In no event shall the consultant, its directors, officers, employees or agents be liable for any special, indirect or consequential damages, including property damage or loss of life, arising out of the use, interpretation or implementation of the data or any information enclosed in the report by any party, including without limitation, loss of profit, loss of production, loss of use, costs of financing, and liability to others for breach of contract.

EXECUTIVE SUMMARY

The Department of Fisheries and Oceans (DFO) Small Craft Harbours (SCH) is planning some important modifications of its Pangnirtung (NU) facilities. In conjunction with the proposed construction, a total maximum of 120,000m^3 (place measure) of material is expected to be dredged and disposed at sea at a site located about 2 kilometres northeast of the dredging site. The disposal site is roughly located in the middle of the Fjord, with nominal depth of about 150m. To assist with Disposal At Sea (DAS) permitting, an oceanographic and sediment dispersion numerical modelling program was undertaken to predict the size of the zone of influence of the disposal operation, in particular TSS dispersion and deposit footprint on the seabed.

A nominal 30-day monitoring program involving measurement of tides, current profiles and physical properties of the water column (temperature and salinity) was designed to provide the basic input to the models. This program revealed large semi-diurnal tides (2m up to almost 8m range from Neap to Spring); a three-layer water column structure with a shallow warm fresh mixed layer in the top 2m, continuous stratification from 2m down to about 40m and a deep cold salty layer from 40m to the bottom. The currents ranged from a few centimetres per second during neap tides to 0.4m/s along channel during peak spring tide. Layering was also present in the water current profiles and a marked intensification of the currents at the bottom was observed during spring tide flood periods. Corresponding surface layer flows would be weak, reaching peak during ebb periods. Significant vertical mixing is thought to occur in Pangnirtung Fjord.

'Typical' current profiles were selected from the data as a basis for five scenarios retained for the model: spring tides flood and ebb, neap tides flood and ebb and slack waters.

Results of the numerical modelling of the dispersion of dredged material show few differences between neap tides and slack waters while a lot more dispersion occurred during spring-flood tides. Overall the TSS plumes are found to spread from a few hundreds of metres to almost a kilometre away from the disposal site and footprint was predicted to be of the order of 500m in diameter and a few mm to 2 to 4cm thick. Surface areas where the thickness of the deposit exceeds 3mm are estimated to be of the order of 10 hectares.

In the order of 15 to 16% of material remains in suspension 15min after an individual dump. Most (99%) of the material remaining in suspension is silt and clay. All gravels settle very quickly as well as most (about 96%) of the medium to fine sand.

Considering that 156,000m^3 (120,000m^3 place measure) of material is to be disposed, a composite footprint was estimated. It consists of a mound with a height just above 2.5m and a diameter of 500m. The footprint extends to a diameter of about 1000m at the edges of which the thickness of the deposit is of the order of few millimetres. This mound should decrease to a height of about 2m maximum after compaction (of the order of a few months).

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1.0 INTRODUCTION

The Department of Fisheries and Oceans (DFO) Small Craft Harbours (SCH) facility at Pangnirtung Harbour, is located on the Pangnirtung fjord southeastern shore, Baffin Island (Nunavut) (Figure 1.1). Important dredging operations are planned at this site, under the supervision of Public Works and Government Services Canada (PWGSC) in order to expand and improve the facilities (additional wharf structure, docks, entrance channel, etc...). AMEC Earth & Environmental (AMEC E&E) was contracted to undertake oceanographic modelling in order to predict the fate of approximately 120,000m^3 place measure of dredging material disposed at a site offshore. The disposal site is located to the North of the harbour (66.170100^{o}N 65. 698900^{o}W NAD83 or 378,35m E 7,341,488m N UTM zone 20) and is expected to accept the majority of material dredged during construction of the harbour channel. The primary objectives of the study are:

- To perform an oceanographic analysis of tides, currents and water column physical properties using data collected during a 2010 field program and review of literature from public archives or provided by PWGSC.
- To map the dispersion of dredged material plume and to determine the size of the footprint as well as the height of the resulting mound over the short-term, taking into consideration the various stages of the tidal cycle.
- To predict the Total Suspended Solids (TSS) levels resulting from the proposed disposal activities

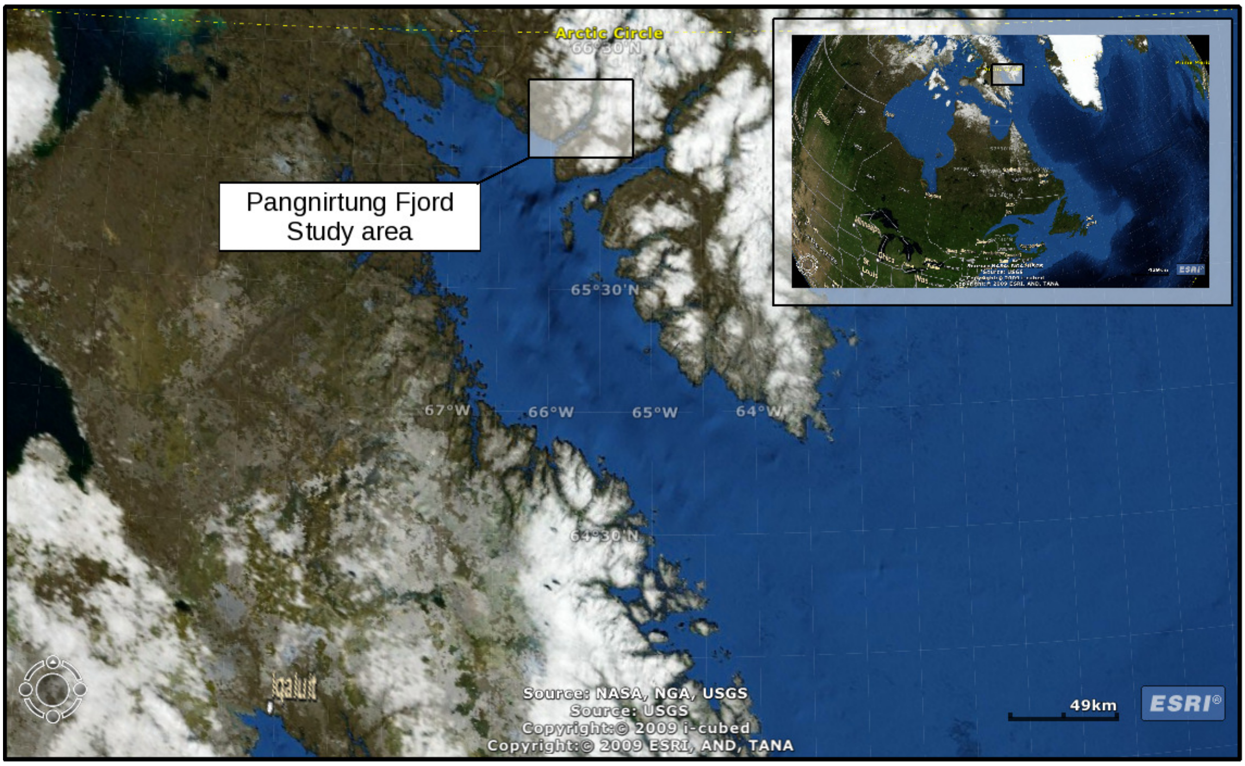


Figure 1 : Study Area

2.0 Oceanographic Background

The Pangnirtung Fjord is approximately 4 km wide at the entrance and 50 km in overall length. A partial high-resolution bathymetric survey of the about half of the fjord (Figure 2) was conducted in 2003-04 by the Canadian Hydrographic Service (CHS). The data are publicly available. The survey shows that the bottom of this fjord is irregular with large deep basins, to maximum of about 150 m Chart Datum (CD) separated by shallower (30 to 60m CD) cross-channel ridges. Pangnirtung fjord is characterized by a very shallow sill (25 to 30m CD) completely bounding its entrance (Figure 2). In addition to the survey, CHS set-up a tide gage station (#4029) from July to September 2008 (TG-CHS on Figure 2). This data set was considered in the design of the monitoring program undertaken by AMEC as a component of the present study.

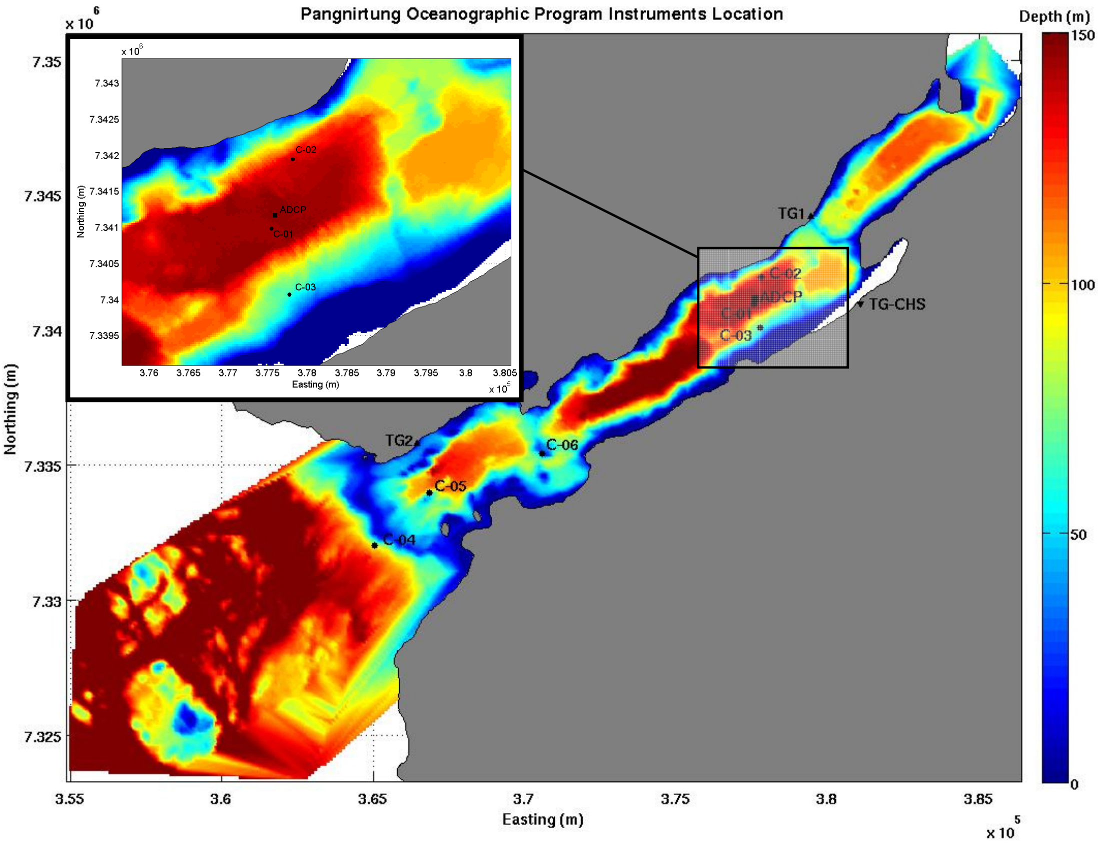


Figure 2: Pangnirtung bathymetry and oceanographic instrumentation location

Significant data gaps were identified in relation to the oceanographic information typically required to support dredged material dumping permit application. An oceanographic monitoring program was conducted to fill the gaps.

In September 2010, two Acoustic Doppler Current Profilers (ADCP) and two water level recorders (TG1 and TG2, Figure 2) were deployed for a nominal 30 day period (late August to early October 2010), to simultaneously acquire time series of current profiles (covering about 80% of the water column) and water levels.

The tide gauges were set to measure water level (pressure) 120 times over one minute, then average and record the results. This cycle was repeated every five minutes. The ADCPs (RDI 300Khz devices) were set to transmit 250 acoustic pings in 2.5 minutes and calculate current velocities for each two-metre vertical division (bins) to derive a ensemble profile of the water column every 15 minutes. Full details of each instrument setup can be found in Appendix A.

Hydrographic profiles of water temperature and salinity were acquired during the September deployment trip using a SeaBird Electronics SBE-Seacat 19plus CTD profiler. Locations of the casts (C-01 to C-06) are shown on Figure 2. The CTD profiles provided insight on the density stratification of the water column which allowed the field team to tune the placement of the ADCP mooring in the field so that potential interaction between the water layers of the fjord would be resolved in the data as well as possible.

2.1 Tides

The tidal regime of Pangnirtung fjord is characterized by large semi-diurnal tides with 5 m mean range (about 2 m neap, almost 8 m spring. Figure 3).

Tidal harmonic analysis was performed on the data using the Matlab T_Tide package (Pawlowicz et al., 2002).

The analysis demonstrated the predominance of tide (above 99%) in the water level signal, largely the semi-diurnal constituents (M2, S2 and N2). Table 1 provides a summary and complete results are in Appendix B.

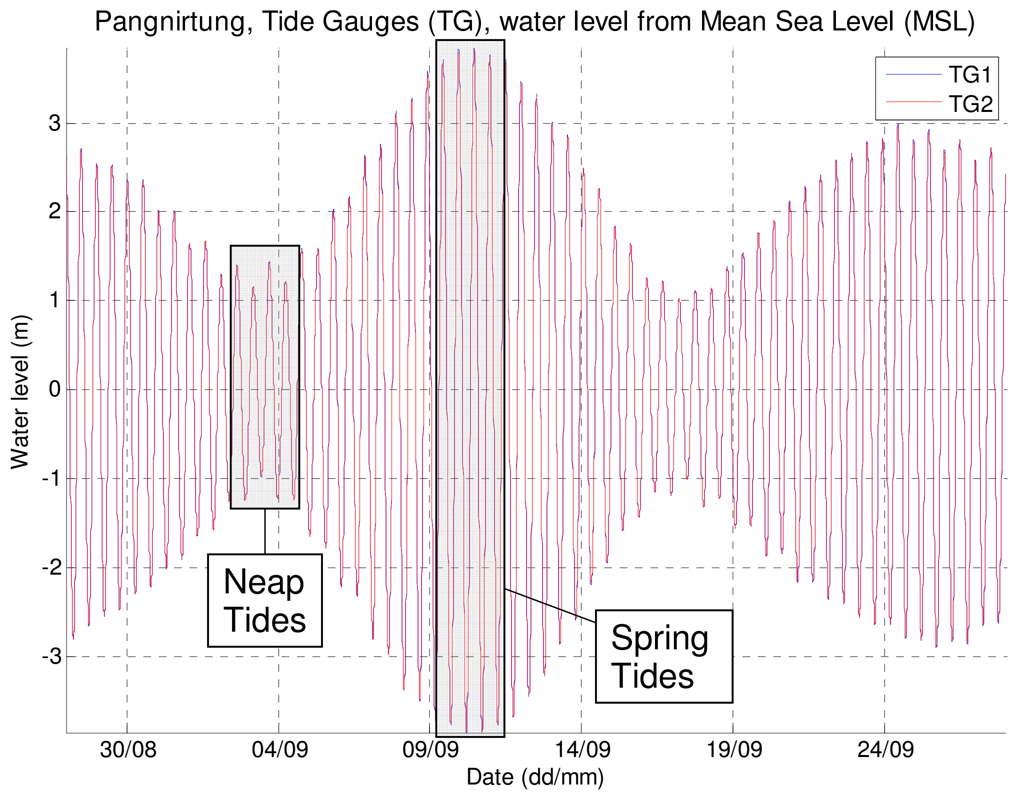


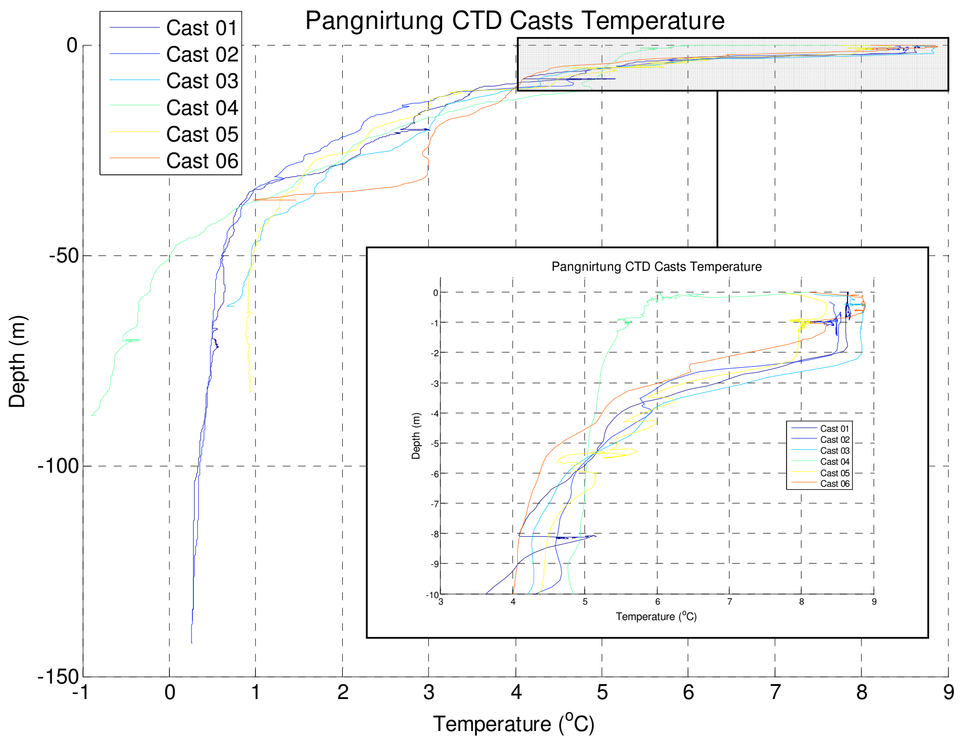
Figure 3: Pangnirtung tides, August to September 2010

Table 1: Tidal harmonic analysis results summary for stronger constituent on AMEC and CHS data

	Amplitude		**Phase**	
	TG1	**TG2**	**TG1**	**TG2**
M2	2.21m	2.19m	287.78°	287.54°
S2	1.04m	1.04m	327.96°	327.66°
N2	0.51m	0.51m	261.41°	261.29°

2.2 Water column physical properties (temperature and salinity)

The water column of Pangnirtung Fjord was characterized in August 2010 for all casts but C-04 (Figure 4), by a very shallow mixed layer in the top 2m or so, with temperature just below 9°C accompanied by very low salinities of about 8 PSU. Down to about 5m, Temperature and Salinity decrease sharply to values of about 5°C and 28 PSU respectively corresponding to a loss of about 1°C per metre and an increase of 6-7 PSU per metre at all stations and assumed here as representative of summer conditions.



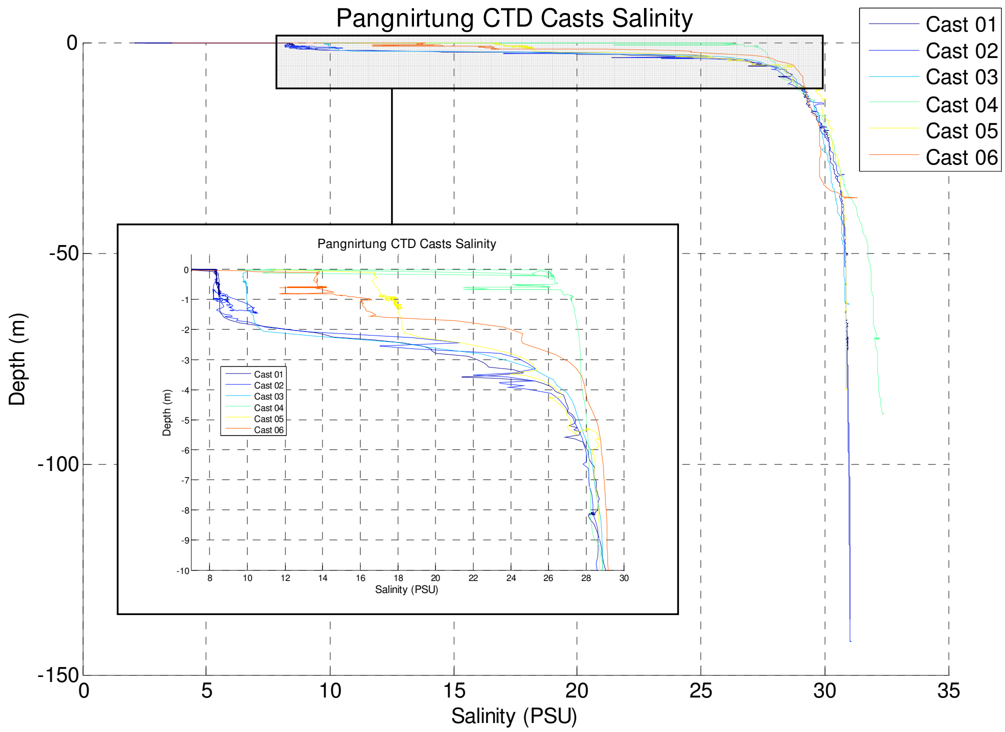


Figure 4: Pangnirtung Fjord Temperature and Salinity Casts (August 2010)

Below 5m, down to about 40m for all the casts but Cast 06, temperature and salinity drops continuously but much less sharply reaching temperatures of about 1°C or less and salinities of about 31 PSU. Cast 6 exhibits a second mixed layer from about 20 to 30m before a sharp decrease of temperature and increase of salinity to the bottom (about 35m).

From 40m to the bottom, the profiles are essentially vertical, demonstrating homogeneous cold (about 0.5°C) and relatively salty (about 31 PSU) characteristics for all but Cast 04. At Station 4, outside the sill, the profile exhibits further decrease of temperature to almost-1°C, and an increase of salinity to above 32 PSU.

At the disposal site, the vertical structure of the water column can be described as a three layer system: a shallow mixed layer in the top 2m, a strongly continuously stratified layer between 2m and 40m (with strongest stratification between 2 and 5m), and a cold salty homogeneous layer below 40 down to the bottom. The shallow top mixed layer is the result of surface mixing due to wind. The presence of the relatively thick continuously stratified layer between 2m and 40m is evidence of vertical mixing occurring at the interface between a warm fresh surface layer and a cold salty bottom layer: in the absence of vertical mixing there would be a very sharp gradient of water properties over a much thinner interface. This continuously stratified layer results from competing processes: fresh water input from glacial melt and rivers, and vertical sheer which allows for entrainment of deep cold salty water into the surface warm fresh water. The balance between the two processes result in typical estuarine or fjord circulation with warm fresh water flowing out at the surface and cold salty water flowing in at the bottom, the resulting vertical sheer in the currents providing energy for entrainment: the more mixing takes place, the more salt needs to be brought in the bottom layer and the more intense is the fjord circulation. At equilibrium, an intermediate layer forms with continuous stratification of properties between those of the cold fresh surface water input and the supply of oceanic sea water. The shallow sill at the entrance of Pangnirtung fjord also probably contributes to the establishment of the fjord circulation and the observed hydrographic structure as vertical mixing occurs over the sill during each tidal cycle. Cast 06 is located on one of the cross-channel sills, where strong vertical mixing appears to occur resulting in a distinct mixed layer between depths of 20 and 30 m. Also to be noted is the constant increase in salinity seaward (from Cast 01-03 toward Cast 04) as well as the evident colder and saltier waters outside the fjord. Overall, the influence of freshwater input and vertical mixing are important factors contributing to Pangnirtung fjord water column characteristics.

2.3 Water column currents

The two RDI-300Khz ADCPs were mounted close together about 80m up from the seabed on a sub-surface mooring with one instrument looking upward (s/n 3464) and the other looking downward (s/n 0247) (setup illustration in Appendix A). This configuration allowed continuous water column current profile measurements from 59m deep up to the surface and from 69m deep down to the bottom (with 6 to 10% rejection close to the surface and the bottom).

Strong tidal influence and multi-layer circulation were expected as typical of a fjord like Pangnirtung, and these features are revealed in the data. A snapshot of the results, highlighting a spring-neap cycle that was further used as base input for the dispersion modelling exercise, can be found in Figure 5. Complete ADCP data sets are presented in Appendix C.

The semi-diurnal tides are evident as a series of ‘stripes’ in Figure 5. Depth-averaged harmonic tidal analyses were also performed on these two ADCP dataset (using T_Tide, Pawlowicz et al., 2002) as with the water level data. The results are presented in Appendix D. Tidal currents are dominant: they account for 75% of the energy in the upward looking ADCP record and close to 90% of the energy in the downward looking ADCP record. As for the water level, the semi-diurnal constituents are dominant.

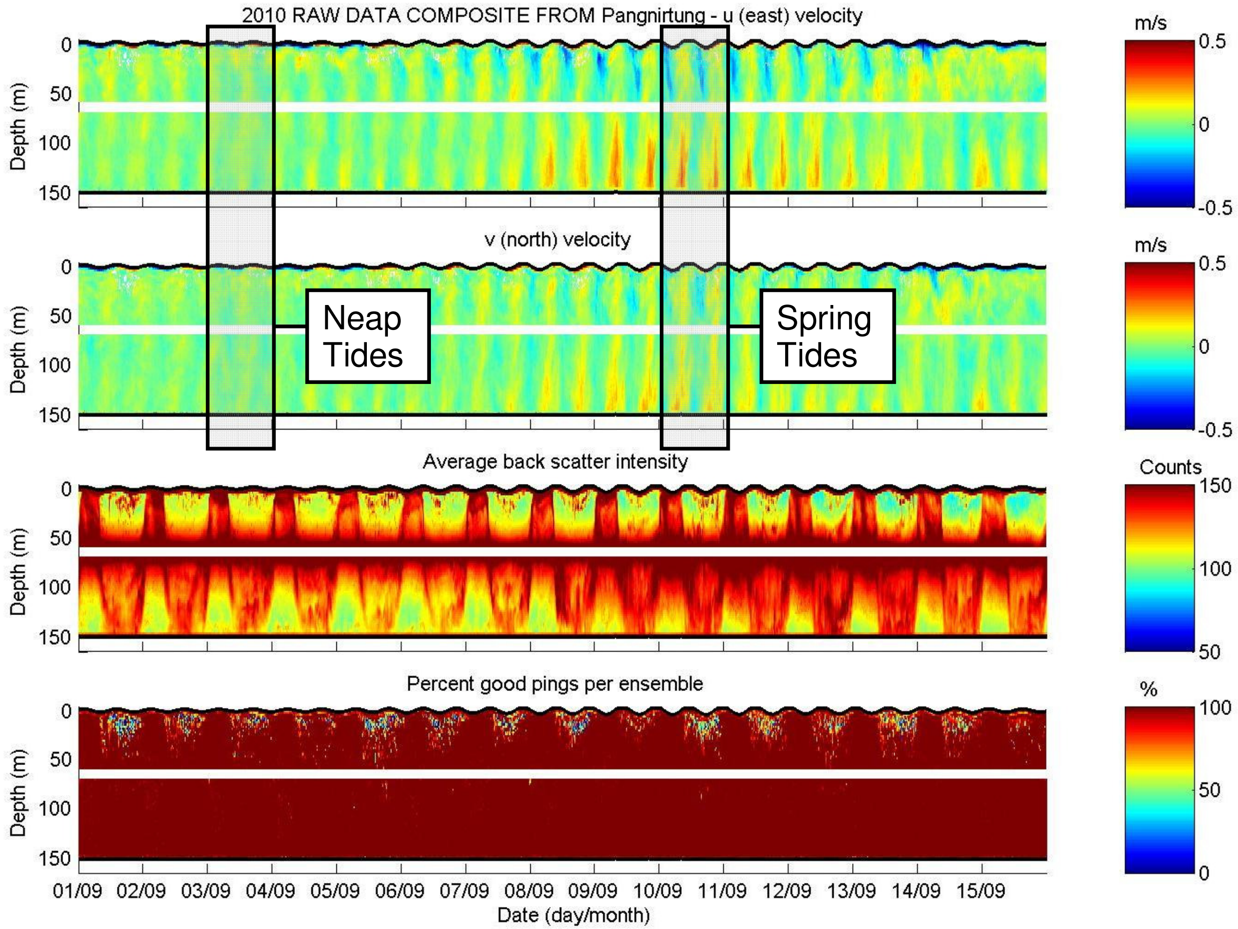


Figure 5: ADCP raw data profiles sample (1st to 16th of September) and 'typical' neap and spring days selected

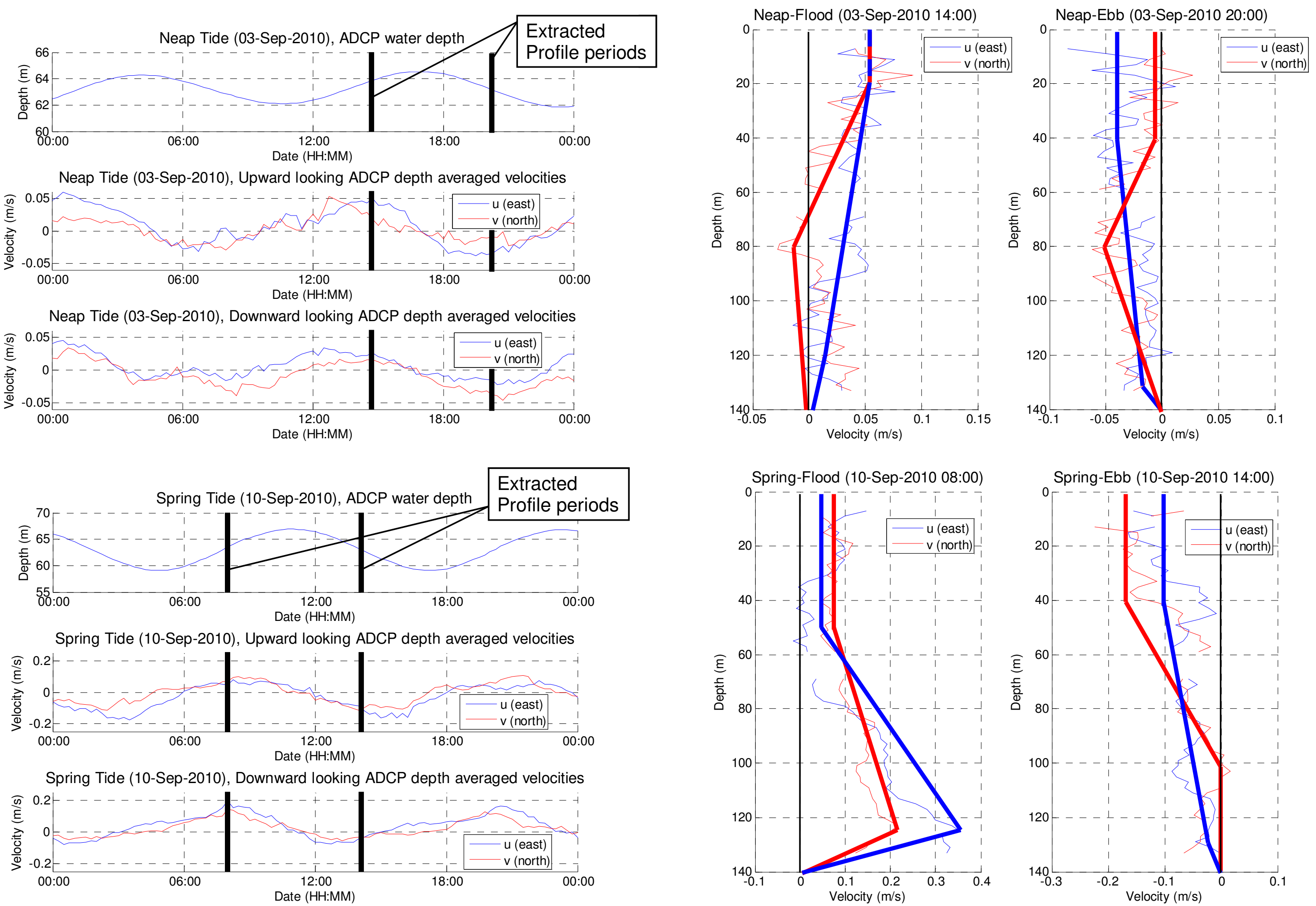


Figure 6: Selected representative Neap and Spring (Flood and Ebb) days depth averaged time-series (upper and lower left) and selected velocity profiles (upper and lower right) as well as model input (bold lines in upper and lower right)

Given the predominance of tidal currents, 'typical' tidal condition were directly extracted from the data and used as accurate and representative input to the dispersion model. Flood and ebb of neap and spring period current profiles were selected respectively on September 3 and September 10 (Figure 6). The profiles were then schematized (bold lines on Figure 6, right side) to satisfy the plume model requirement for a '2 point velocity profile' current profile input.

Overall, neap tide currents are weak, of the order of few centimetres per second and reaching a maximum of about 5 (cm/s) in u and v components in the upper part of the water column (Figure 6). Spring tides currents are more significant, of the order of 10's of centimetres per second, especially on the bottom part of the water column, reaching maximums of about 35 cm/s in u and 20 cm/s in v.

A remarkable feature to be noted is the large asymmetry between flood and ebb during spring tides, the ebb flow being almost nonexistent in the bottom part of the water column (velocities around 0) while reaching a maximum on the upper part (velocities around 0.1m/s to 0.2m/s, that is stronger than during the flood). As explained in Section 2.2, this is most likely due to some intensification of the estuarine circulation as stronger spring currents allow for more vertical mixing over the sill and cross-fjord ridges.

3.0 MODELING METHODOLOGY AND INPUTS

Dredge material disposal in an open-water operation commonly introduces suspended sediment into the water column. Typically, at the disposal site, the dredge material falls through the water column as a well-defined jet of high-density fluid which may contain a block of solid material.

In the case of a bucket or clamshell type dredging operation, the material is collected at nearly its *in situ* density and placed in barges or scows for transportation. The disposal generally occurs as a series of discrete discharges or dumps. The dredged material may be slurry, but oftentimes sediment remains in fairly large consolidated clumps and reaches the seabed in this form. Whatever its form however, the dredged material descends rapidly through the water column to the bottom with only a small amount of the material remaining in suspension.

The ADDAMS-STFATE (Short Term FATE) model was originally developed by Brandsma and Divoky (1976), and is based on the work by Koh and Chang (1973). STFATE aims to describe the short-term behaviour of dredge material dump in a channel or open water site.

Koh & Chang (1973) describe 3 phases when a slug of material is released in water. These are:

- a convective descent phase during which the dump cloud or jet falls under the influence of gravity;
- a dynamic collapse phase occurring when the descending cloud or jet either impacts the bottom or arrives at a level of neutral buoyancy (dominance of spreading), and;

- a passive transport-dispersion phase commencing when the material transport and spreading are determined more by ambient currents and turbulence than by the dynamics of the disposal operation.

3.1 Dredging and dumping method and schedule

Details of the planned dredging activity were provided to AMEC by PWGSC. The following information was used to develop modelling scenarios to predict as closely as possible, the footprint of the proposed operation under realistic conditions:

- Dredging is to be done by means of clamshell dredge unloading into barges
- 156,000 m^3 of material in total to be dumped at sea. This estimate includes an over-dredging factor of 0.4 metres for both the channel, basin and side slopes, and is bulked up by a factor of 30% to account for the entrainment of sea-water typical of clamshell operations (from an original, place measure amount of 120,000 m^3).
- Dredged material will be transported and disposed of at sea by bottom-dump split hull scow barges 55m long, 9m wide, 4m deep of 1529 m^3 capacity
- Dredging operations would be undertaken 6 days per week with two 8-hour shifts per day for 12 weeks. The scow/barge dump would be 1500 cubic metres per dump for an estimated 2 dumps per day.
- The barge will travel northeasterly to the disposal site, 66.170100°N 65. 698900°W NAD83 (or 378,35m E 7,341,488m N; UTM zone 20), at an approximate speed of 1.8m/s via the most direct navigational route (Figure 7).

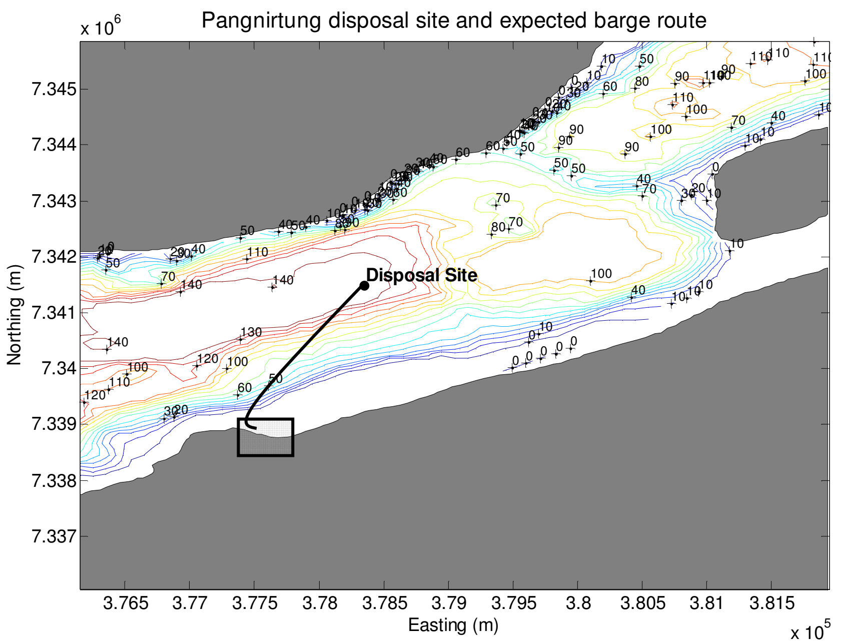


Figure 7: Disposal Site and barge route expected

3.2 Dredged material characteristics

Borehole and surface sediment samples were taken within the channel dredging area during previous geotechnical studies (Soil-Mat, 2009 and EBA, 2007). The results of these reports are summarized in Table 2.

Table 2: Summary of Sediment Sampling Reports

Study	Sample type	Gravel	Sand	Silt	Clay
Soil-Mat (2009)	Borehole*	6.1%	82.5%	8.8%	2.7%
EBA (2007)	Borehole**	11.5%	71.5%	16%	4%
	Surface*	10%	72.5%	15%	2.5%
* located in channel ** located both in channel and harbour basin					

The material to be deposited at sea will mainly come from the channel area. This material is characterized as sand/silty sand with occasional deposits of silty clay material. Overall, the material condition was found to be relatively compact to dense at most sites.

In addition to grain size characteristics, moisture content was also measured for the EBA (2007) samples and found to be between about 12% (boreholes) to 15% (surface); equivalent to a porosity of 31.2% to 39% (considering water density of 1kg/l and sediment density of 2.6kg/l).

These results were combined to form the following input values for each of the STFATE model runs (Table 3). This input scenario considers an in-situ porosity of 30% (equivalent to moisture content of about 12%), and that the dredge material would contain an additional 30% of sea-water. In all, the dumped material would contain 49% solid material and 51% of seawater.

Table 3: Dredge material characteristics input into STFATE

Description	%Total Sample (dry)	Specific Gravity	Volumetric Concentration*	Fall Velocity (ft/s)	Character
Gravel	10	2.7	0.049	1	Non cohesive
Sand	80	2.7	0.392	0.06	Non cohesive
Silt	8	2.65	0.0392	0.01	Cohesive
Clay	2	2.65	0.0098	0.002	Cohesive
* a value of 1 corresponding to 100% Interstitial seawater density assumed: 1.014 (g/cc)					

3.3 Dumping site characteristics

Considering the oceanographic background conditions described in section 2.0, the following simplifications and assumptions were made to suit STFATE input requirements:

- Depth at the disposal site is assumed to be 150m and constant for all scenarios; this corresponds to the disposal site estimated Mean Sea Level (MSL).
- The water column is considered stratified as follows (Table 4)

Table 4: STFATE disposal site water column physical properties input

Depth	Density (g/cc)	Corresponding	
		Temperature (°C)	Salinity (PSU)
0m	1.007	8	9
5m	1.022	5	28
50	1.025	1	31
150	1.0260	0.5	32

- Five different tidal scenarios are considered:
  - neap tide, flood conditions
  - neap tide, ebb conditions
  - spring tide, flood conditions
  - spring tide, ebb conditions
  - slack water (neap or spring conditions)

- the velocity profile is schematized as a '2-point velocity profile for a constant depth grid' as illustrated in Figure 6 and summarized in Table 5 for the different scenarios considered.

Table 5: STFATE velocity profiles scenarios input

Description	Depth	v (m/s)	Depth	u (m/s)
Neap-Flood	66ft (20m)	0.06	20m	0.06
	262ft (80m)	-0.01	120m	0.02
Neap-Ebb	131ft (40m)	-0.01	60m	-0.04
	262ft (80m)	-0.06	130m	-0.02
Spring-Flood	164ft (50m)	0.075	50m	0.05
	400ft (122m)	0.2	130m	0.35
Spring-Ebb	131ft (40m)	-0.15	40m	-0.1
	328ft (100m)	0	130m	0.025
Slack (high or low tide)	0ft (0m)	0	0ft (0m)	0
	500ft (150m)	0	500ft (150m)	0

4.0 MODELING RESULTS

The STFATE model was run using the tidal and current conditions of five characteristic tide phases: spring flood and ebb, neap flood and ebb and slack tide as described in section 3.3 and Table 5. The dump, dispersion plume and sea-bottom footprint simulation of a single 1500m^3 split-hull barge of material, as described in section 3.1 was undertaken for each of the tide forcing scenarios. A final ‘composite’ footprint was estimated based on the total of material to be disposed (Figure 13).

Results for each individual scenario can be found in Figure 8 to Figure 12 while Table 6 summarizes and compares the different scenarios. Each of the main dispersion figures represents a composite image of the plume after 1 hr simulation run. Additionally, the three plots at the bottom of the figure represent the evolution of the plume concentration for the different phases considered by STFATE (convection, collapse and passive-diffusion of the long-term plume). All the concentrations estimates are ‘plume-averaged’, that is, the entire mass of solids present in a given plume (or clouds as defined by STFATE) was divided by its volume to yield TSS units of mg/l. In reality, concentrations in the clouds are represented by a Gaussian distribution and higher concentration should be expected at the cloud centre. Figure 8 to Figure 12 also provide a footprint (thickness of the deposit in metres) of material settled on the sea-bottom (upper left inset) as well as a 3D view of the composite plume to illustrate its vertical structure (upper right inset).

For all scenarios, it takes about a minute and half (100sec) for the material to reach the bottom (convection phase) and almost another minute to spread out (80sec) during the collapse phase. During both phases, TSS concentration is extremely high from its original concentration of about 1300 g/l to less than 10 g/l. As can be seen on the concentration plots at the bottom, gravel and sand concentration decrease very quickly during the collapse phase while silt and clay remain almost constant. As expected, the spreading of the long-term plume, as well as the bottom footprint, is significantly higher under high current regimes (i.e: spring tides), notably during spring-flood. It is also interesting to note that while for the spring-flood scenario practically the entire cloud is transported in the bottom layer of the water column (below 100m deep), some material remains in the upper layer during the spring-ebb scenario. This is thought to be due to the fact that the barge was considered to be moving North-East for all scenarios, so against the tide during ebb.

Overall, the plumes are found to spread from few hundreds of metres to almost a kilometre away from the disposal site. Neap-flood, neap-ebb and slack are practically equivalent while the spring-flood scenario spreads the most. It should be noted however that, due to local bathymetry, it is thought that the plume would be more likely confined to the depression in which the disposal site is located (where depth is in excess of 100m).
The footprints are found to be of the order of 500m diameter with thickness ranging from a few millimetres to about 4cm. The grey areas around the mound of the footprint figures represent deposition of less than 0.03mm. Surface areas where the thickness of the deposit exceeds 3mm are estimated to be of the order of 10 hectares for all scenarios considered.

In the order of 15 to 16% of material remains in suspension after 15min of an individual dump event, most of it being silt and clay (99% remaining in suspension). All gravels settle very quickly as well as most (about 96%) of the (medium to fine) sand. Since currents are considered constant with STFATE, most of the material that hasn't settled during this first period is unlikely to settle later and relatively little change occurs after an hour of simulation: the proportion of sand diminishes a little, but most of the silts and clays remain suspended, leaving about 12 to 14% of material in the water column.

Finally, considering that 156,000m^3 of material is to be disposed, it would require 104 loads of 1,500m^3 single barge dumps to complete the proposed project. Assuming a typical day with 2 floods, 2 ebbs and 4 slacks tide periods, and assuming that all the barges would be unloading at the exact same location, a composite footprint was estimated adding 13 spring and 13 neap flood, 13 spring and 13 neap ebb and 52 slack bottom footprint thicknesses. The result (Figure 13) demonstrates a 500m diameter for the most part, with a maximum height just above 2.5m. The area with an estimated thickness of one millimetre or more extends to a diameter of about 1000m or an area of about 70 hectares.

Since the deposited void ratio considered here was about 1.08 (that is a porosity of about 52%) and that the natural, more compacted, *in-situ* sediment would eventually have a void ratio of about 0.67 (or a porosity of about 40%), the resulting mount should decrease to a height of about 2m maximum (about 80% of its initial value) after compaction period (with the majority of compaction occurring within a period of 2 to 3 months).

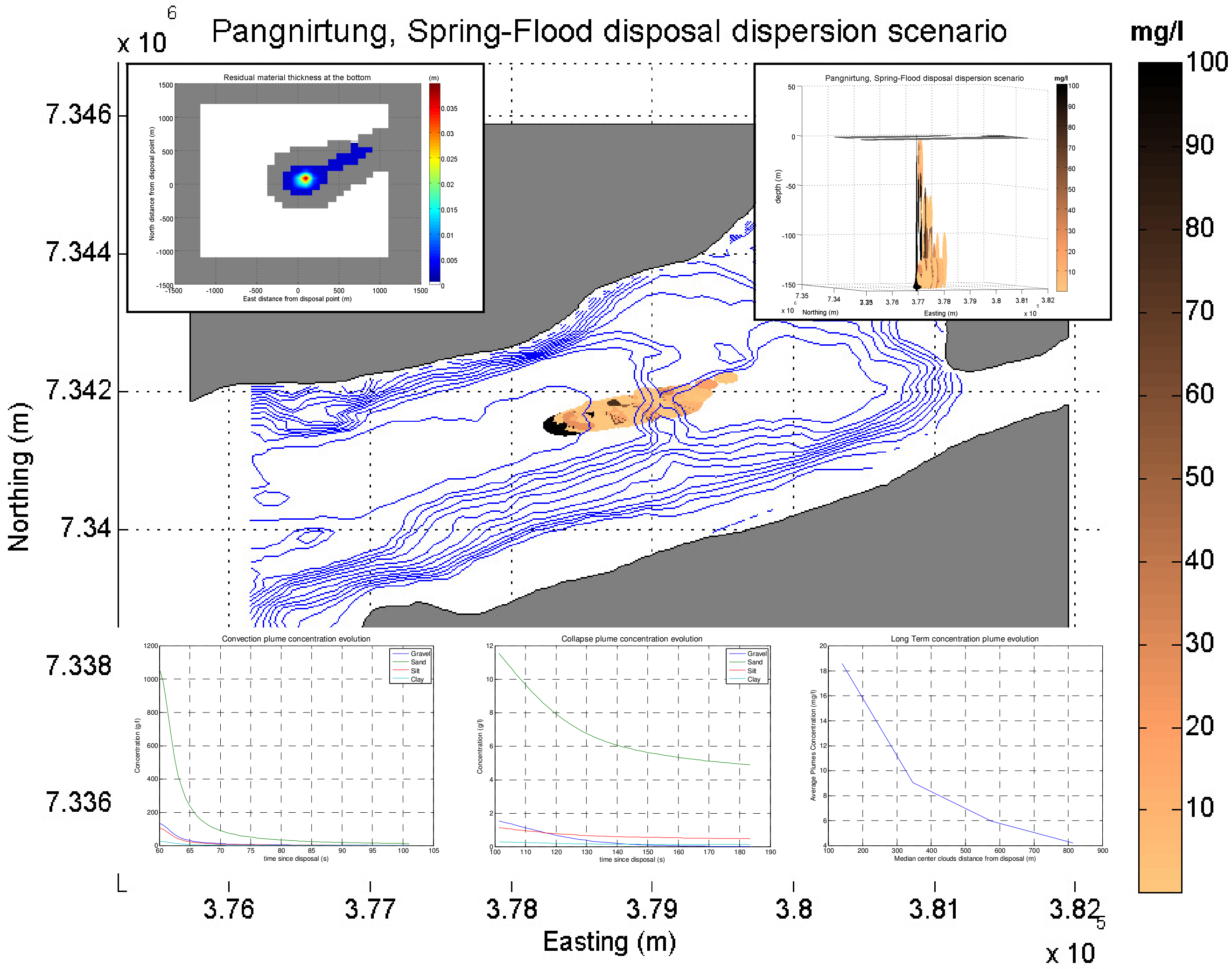


Figure 8: Spring-Flood dispersion and deposition scenario results

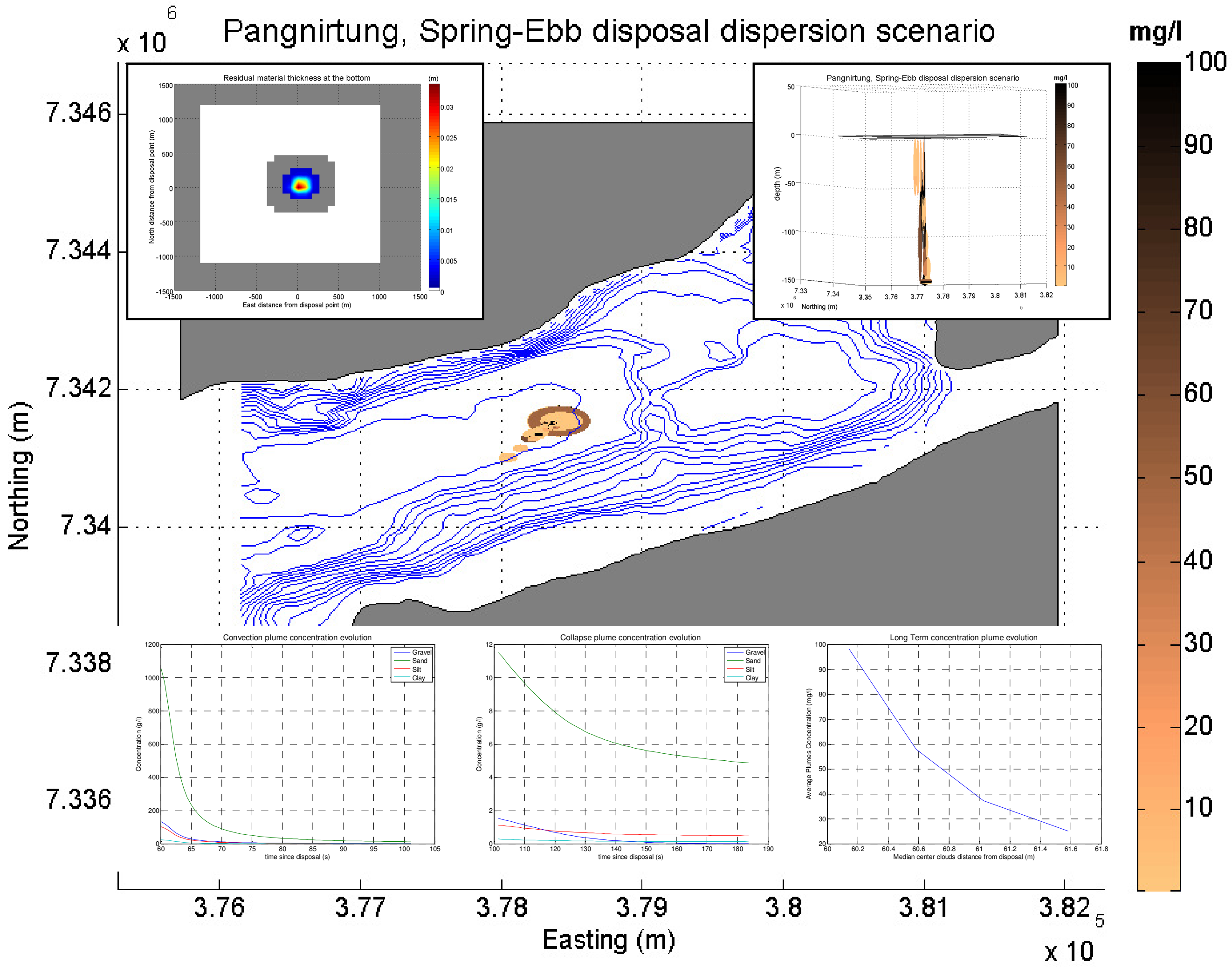


Figure 9: Spring-Ebb dispersion and deposition scenario results

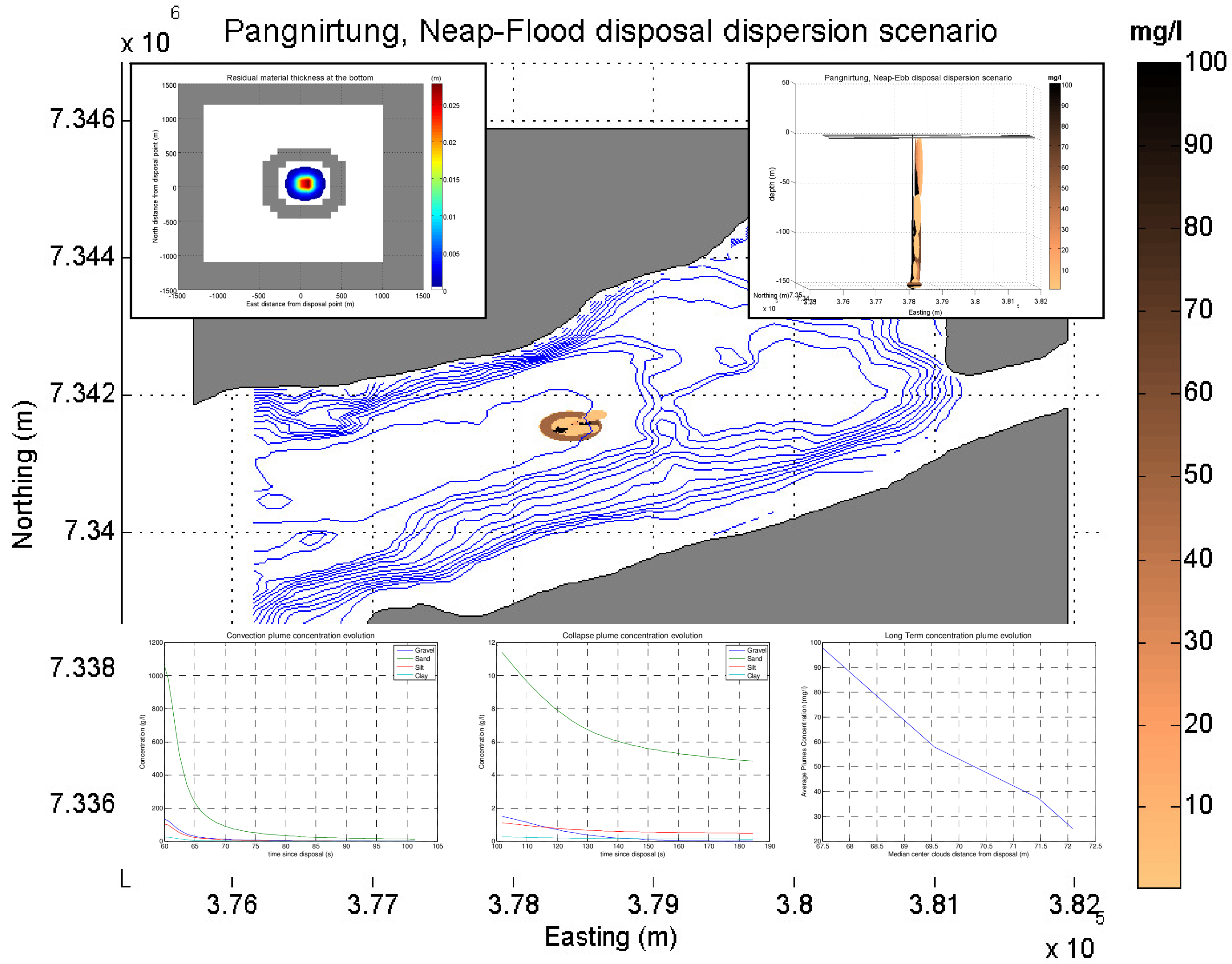


Figure 10: Neap-Flood dispersion and deposition scenario results

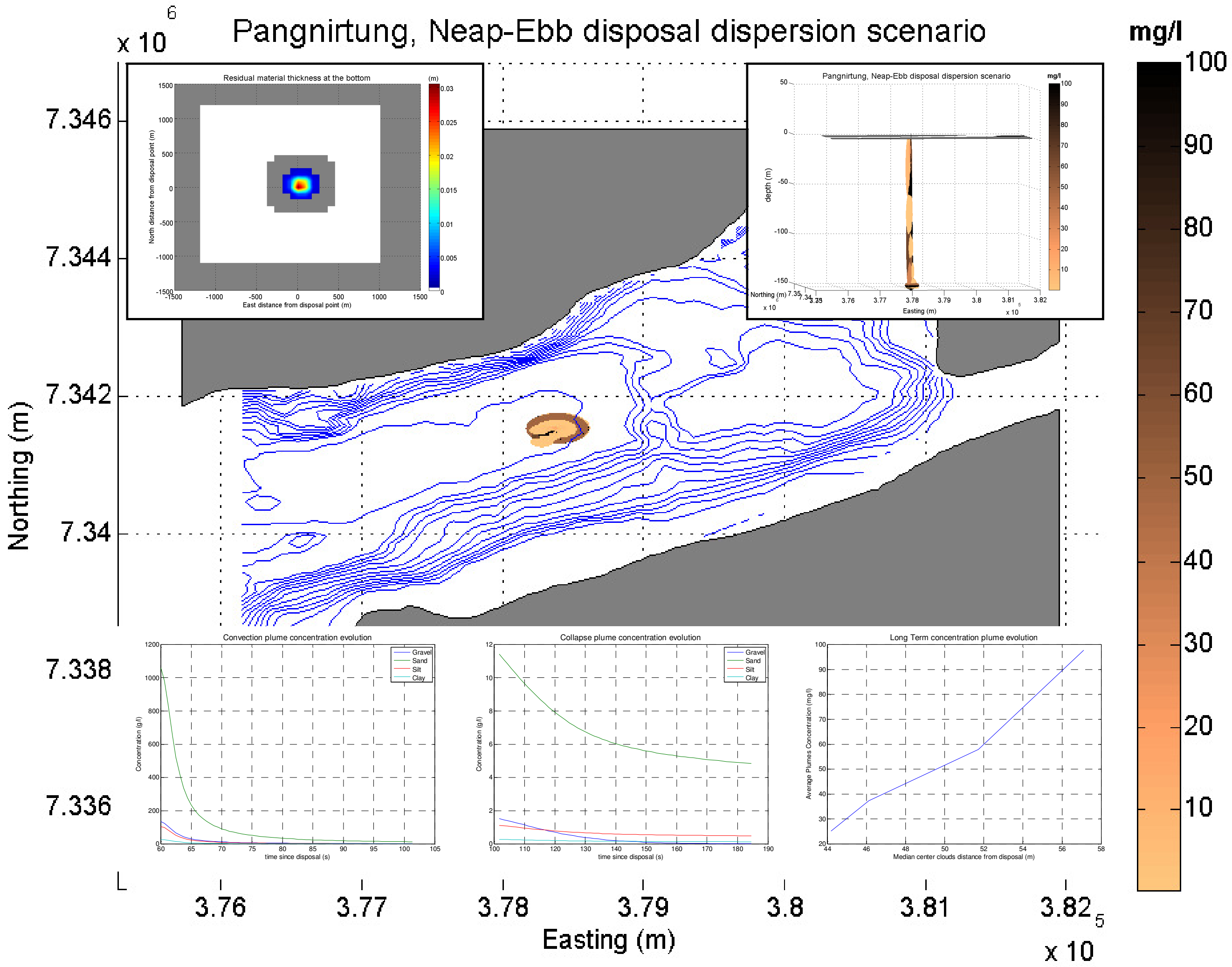


Figure 11: Neap-Ebb dispersion and deposition scenario results

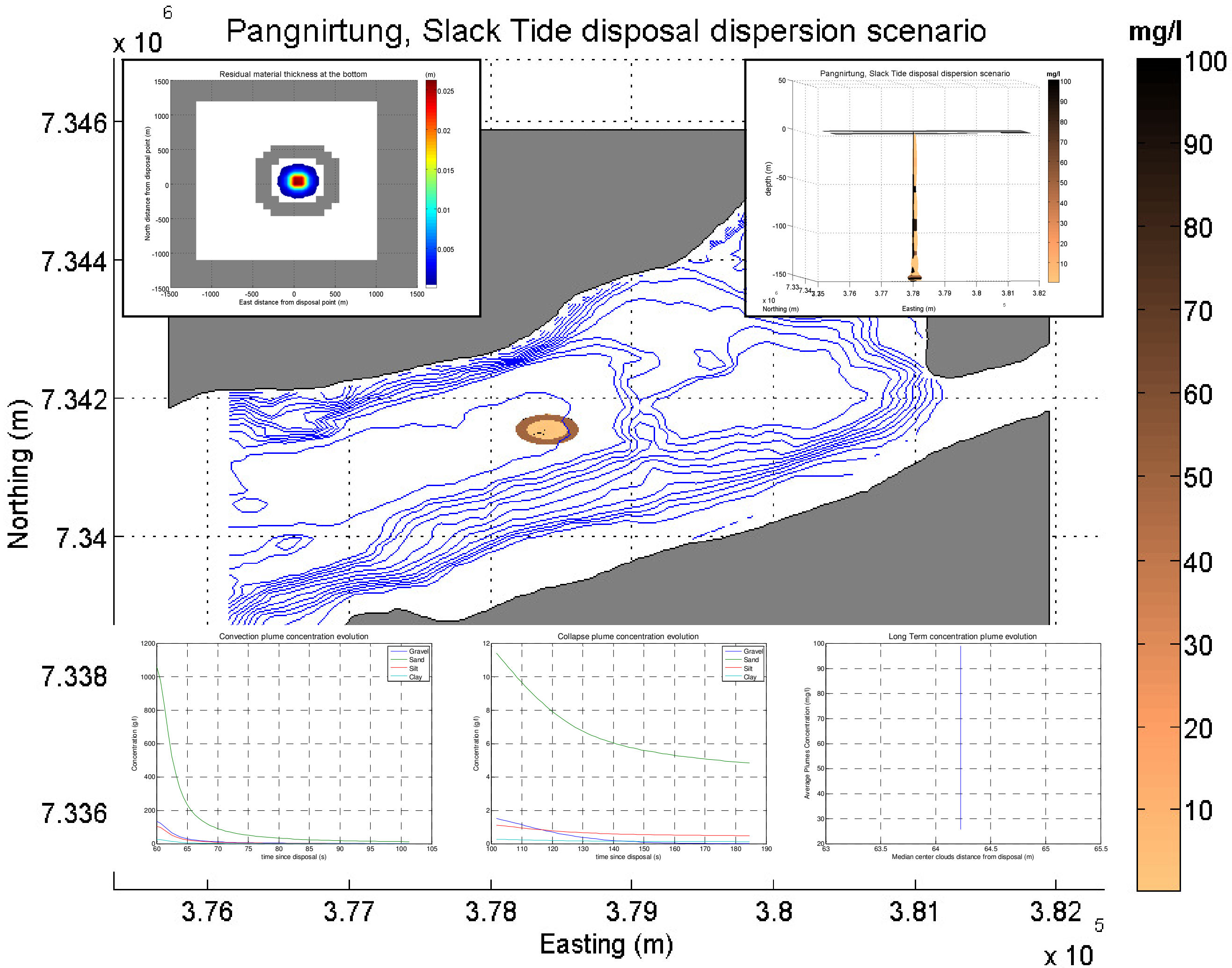


Figure 12: Slack Tide dispersion and deposition scenario results

Table 6: Dispersion and Disposal summary results

Scenario	Dispersion Results after 15min (900s)			Dispersion Results after 1hr (3600s)			Footprint Results (after 1hr -3600s-)		
	Suspended (m^3)	Settled (m^3)	% Suspended	Suspended (m^3)	Settled (m^3)	% Suspended	Maximum thickness (cm)	Average Thickness (cm)	Area (ha) >3mm
Spring-Flood							3.96	1.11	9.2
Gravel	0	74.93	0	0	74.93	0			
Sand	48.88	550.54	8.16	21.68	577.72	3.62			
Silt	59.77	0.18	99.70	59.70	0.24	99.60			
Clay	14.97	0.01	99.93	14.96	0.02	99.84			
Total	**123.62**	**625.65**	**16.50**	**96.34**	**652.91**	**12.86**			
Spring-Ebb							3.35	1.09	10.03
Gravel	0	74.93	0	0	74.93	0			
Sand	39.28	560.14	6.55	26.14	573.27	4.36			
Silt	59.24	0.70	98.84	57.99	1.94	96.76			
Clay	14.95	0.04	99.74	14.86	0.12	99.18			
Total	**113.47**	**635.80**	**15.14**	**99**	**650.27**	**13.21**			
Neap-Flood							2.77	1.22	10.03
Gravel	0	74.93	0	0	74.93	0			
Sand	39.42	559.99	6.58	26.42	572	4.41			
Silt	59.25	0.69	98.85	58.02	1.93	96.79			
Clay	14.95	0.04	99.75	14.86	0.12	99.19			
Total	**113.62**	**635.65**	**15.16**	**99.3**	**649.96**	**13.25**			
Neap-Ebb							3.05	1.07	10.03
Gravel	0	74.93	0	0	74.93	0			
Sand	39.52	559.88	6.59	26.43	572.96	4.41			
Silt	59.25	0.69	98.85	58.02	1.92	96.79			
Clay	14.95	0.04	99.75	14.86	0.12	99.19			
Total	**113.72**	**635.53**	**15.18**	**99.31**	**649.94**	**13.26**			
Slack							2.62	1.22	10.03
Gravel	0	74.93	0	0	74.93	0			
Sand	39.49	559.91	6.59	26.43	572.99	4.41			
Silt	59.25	0.69	98.85	58.02	1.92	96.79			
Clay	14.95	0.04	99.75	14.86	0.12	99.19			
Total	**113.69**	**635.56**	**15.18**	**99.31**	**649.96**	**13.25**			

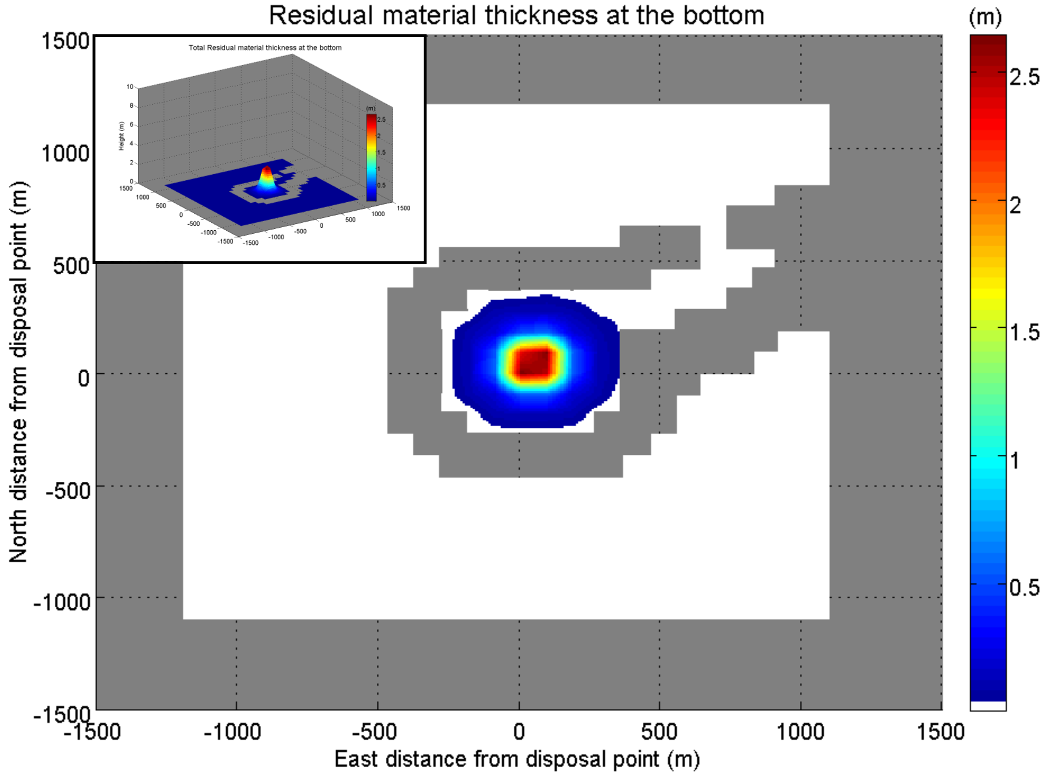


Figure 13: composite total residual deposit thickness after 156,000m^3 of unloaded material

5.0 References

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Pawlowicz R., Beardsley B. and Lentz S., 2002. Classical Tidal Harmonic Analysis Including Error Estimates in MATLAB using T_TIDE, Computers and Geosciences, 28 (2002), pp. 929-937.

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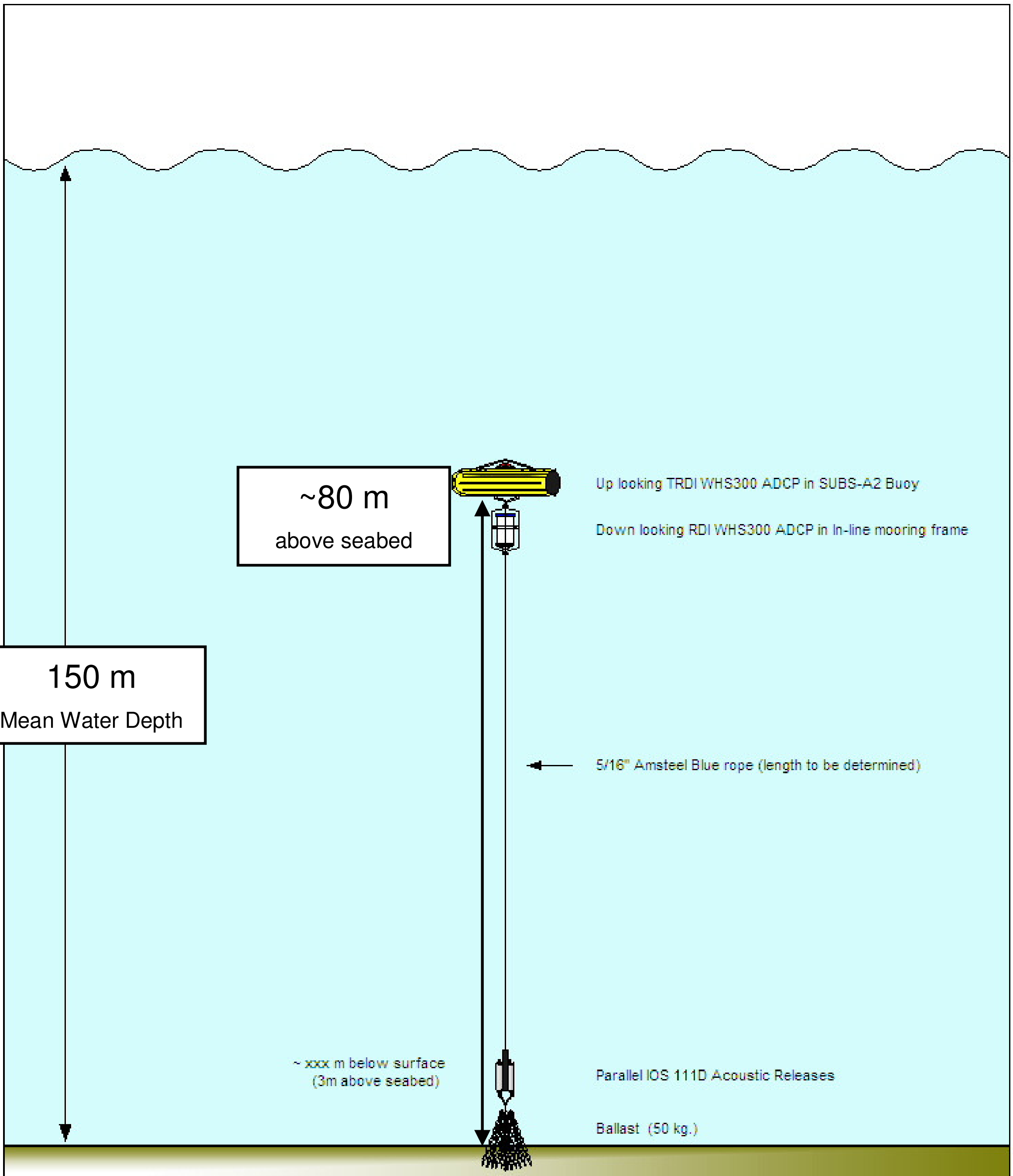
APPENDIX A

Instruments Set-Up log sheets



amec Earth & Environmental	Pangnirtung Ocean Disposal Study	DESCRIPTION: Current meter mooring		
		SCALE: Not to Scale	Drawing: TV01050-001	CREATED: 23 July 2010

DEPLOYMENT LOG

amec

RBR Model TWR-2050 Tide & Wave Recorder

Project No TV01050 **Client** PWGSC / DFO
Location Pangnirtung

Instrument Details

Instrument Serial No 15445
Firmware version 6.51

Sensor	Range	Accuracy	Resolution
Pressure	0-20 dBar	±1 cm.	0.2 mm
Temperature	-5 to +35°C	±0.002°C	<0.00005°C

Max. safe deployment depth 40 dBar
Memory size 8 Meg Bytes New battery installed ~~Yes~~ / (No) Voltage 5.88
Comm. settings 19200,8,N,1 Comm. Settings (If different)

Deployment Settings

Expected mean depth - 10.0 m
Expected height above - 0.00 m

Start Time 2010/Aug/15 00:00:00 yy/mm/dd, hh:mm:ss
End Time 2011/Aug/15 00:00:00 yy/mm/dd, hh:mm:ss

Sample rate for tide & wave data	2 (Hz)	Enable Wave Data	~~Yes~~ / (No)
Enable Averaging	Yes / No	Sample Period for Waves	– (hh:mm:ss)
Sample Period for Tide	00:05:00 (hh:mm:ss)	Burst Length	– (samples)
Averaging Time for Tide	00:01:00 (hh:mm:ss)		
Estimates			
Memory usage	7.5 (%)	Wave Analysis Bandwidth	– (Hz)
Battery usage	1677 (mAH)	Wave Periods	– (Sec.)

Deployment

Time set to GMT Yes
Water depth 10 m (Sounded) Instrument depth 10 m
Coordinates (deg onshore {379,439 E / 7,344,222 N} | offshore {379,440 E / 7,344,206 N} Datum UTM zone 20, NAD83
Instrument submerged 923 (EDT) 1323 (GMT) Vessel Silver Dolphin III - Shaaka -
Senior Tech. Date 27-Aug-2010

Recovery

Time out of water (yy/mm/dd,hh:mm) 2010/09/28 1300(EDT) ~~GMT~~ 1700 GMT Clock error None (1s)
Time turned off (yy/mm/dd,hh:mm) 2010/09/28 ~~[illegible]~~ 2122 GMT Data file name 015445_PANG.dat .hex
Senior Tech. (sign) SD. Date 2010/09/28 Vessel Shaaka!

Comments

Site 1: Upper Fjord Portion (close to Pang).
Seems like good quality data; No missing ensemble.(12,929)

DEPLOYMENT LOG

amec

RBR Model TWR-2050 Tide & Wave Recorder

Project No TV01050 **Client** PWGSC / DFO
Location Pangnirtung

Instrument Details

Instrument Serial No 15444
Firmware version 6.51

Sensor	Range	Accuracy	Resolution
Pressure	0-20 dBar	±1 cm.	0.2 mm
Temperature	-5 to +35°C	±0.002°C	<0.00005°C

Max. safe deployment depth 40 dBar
Memory size 8 Meg Bytes — New battery installed ~~Yes~~ / (No) — Voltage ~~6.09~~ 5.88 Vdc V
Comm. settings 19200,8,N,1 — Comm. Settings (If different)

Deployment Settings

Expected mean depth - 10.0 m
Expected height above - 0.00 m

Start Time 2010 / Aug / 15 00 : 00 : 00 yy/mm/dd, hh:mm:ss
End Time 2011 / Aug / 15 00 : 00 : 00 yy/mm/dd, hh:mm:ss

Sample rate for tide & wave data 2 (Hz) — Enable Wave Data ~~Yes~~ / (No)
Enable Averaging (Yes) / ~~No~~ — Sample Period for Waves - (hh:mm:ss)
Sample Period for Tide 00 : 05 : 00 (hh:mm:ss) — Burst Length - (samples)
Averaging Time for Tide 00 : 01 : 00 (hh:mm:ss)

Estimates
Memory usage 7.5 (%) — Wave Analysis Bandwidth - (Hz)
Battery usage 1674 (mAH) — Wave Periods (Sec.)

Deployment

Time set to GMT Yes
Water depth ~3-5 m ~~Sounded~~ / Eye in Sounder Not in Fathoms — Instrument depth ~3-5 m
Coordinates (deg 366,~~433~~ E ; 7,335,810 N — Datum UTM zone 20, NAD83
Instrument submerged ~1230 EDT ; 630 GMT — Vessel Shaaka ("Silver Dolphin III")
Senior Tech. — Date 27 · Aug · 2010

Recovery

Time out of water (yy/mm/dd,hh:mm) 2010/09/28 1331 EDT 1731 GMT — Clock error none (1s)
Time turned off (yy/mm/dd,hh:mm) 2010/09/28 2202 GMT — Data file name 015444_PANG.dat .hex
Senior Tech. (sign) [signature] — Date 28 · Sep 2010 — Vessel Shaaka!

Comments

Site 2 (Seb'wave) : Down Fjord portion (close to mouth or sill)
Seems like good quality data set; No missing ensemble (12,937)

DEPLOYMENT LOG

amec

RD Instruments Workhorse ADCP

Project No TV01050 Client PWGSC DFO
Location (Rig & Well Site) Pangnirtung

Instrument Details

Model	(Sentinel)/ ~~Long Ranger~~	Frequency	300 (kHz)	Instrument Serial No	0247
Firmware version	50.38	Memory size (MB)	(PC card 1)	(PC card 2)	
Depth rating (m)		Pressure sensor fitted	Yes / No	Sensor depth rating (m)	
Comm. settings	RS232,9600,8,N,1	Comm. Settings (If different)	—		
New battery	(Yes) No Voltage 44.6	External batteries (Quantity)	— Voltage —	Initials M.B	Date 3 Aug 10

PlanADCP

Variable			Result		Result	
Command file name	pangnirtung2_SEB.txt	First cell range	4.15 m	Power usage	579.65 wH	
Water temperature	5 °C	Last cell range	132.15 m	Battery pack usage	1.3	
Salinity	35 ppt	Maximum range	128.11 m			
Transducer depth	0 m	Standard Deviation	0.92 cm/sec			
Magnetic Declination	0 °	Ensemble size	1454 Bytes			
Deployment duration	55 days	Storage space required	7.32 MB	Initials	SD	Date 25-Aug-2010

Command Summary

CF	11101	Flow control	WD	111100000	Data output (v,c,a,pg,st,p0,p1,p2,p3)
BM	—	Bottom Track mode	WF	176	Blank after transmit (cm)
BP	—	Bottom Track pings/ensemble	WN	65	Number of depth cells
BX	—	Maximum Tracking depth (dm)	WP	250	Water track pings/ensemble
EA	0	Heading alignment (1/100 th deg)	WS	200	Depth cell size (cm)
EB	0	Heading bias (1/100 th deg)	WV	175	Ambiguity velocity
ED	0	Transducer depth (dm)	TE	00:15:00.00	Time per ensemble (hh:mm:ss.ss)
ES	35	Salinity (ppt)	TP	00:00.60	Time per ping (mm:ss.ss)
EX	11111	Coordinate xform	TF	10/08/25 21:05:00	Time of first ping (yy/mm/dd,hh:mm:ss)
EZ	1111101	Sensor source (c,d,h,p,r,s,t)	CK	✓	Keep parameters as user defaults
WB	1	Mode 1 bandwidth control (~~0=wide~~, 1=narrow)	CS	✓	Start deployment
RN	—	Set deployment name (SMMYY: Site, Mo,Yr)			(Other commands)
WA	50	False Target Threshold			Initials SD Date 25-Aug-2010

Deployment

Deployed Orientation ~~Upward~~ /(Downward) Mode (Self-contained) / ~~Telemetry~~ (Note: If telemetry, complete 'Telemetry Log Sheet'.)

ADCP set to GMT	Yes	Memory erased	
Pinging confirmed	YES		
Water depth	~150 m ~~Sounded~~ / Charted	Instrument depth	~60 65 m
Coordinates (deg min.min)	377,562 E; 7,341,144 N @ ~40m NE	Datum	UTM zone 20, NAD83
Range/Bearing (from platform)	n.m. ° True	Magnetic Variation	—
Instrument submerged (yy/mm/dd,hh:mm)	2010-08-25 19:45 EDT ~~GMT~~	Vessel	Silver Dolphin III
Senior Tech. (sign)	[signature]	Date	25-Aug-2010

Recovery

Time out of water (yy/mm/dd,hh:mm)	10/09/28, 1401 EDT (1801 GMT)	Clock error	None Found (1 sec)
Time turned off (yy/mm/dd,hh:mm)	10/09/29, 00:35 GMT	Data file name	RDI 001.000
Senior Tech. (sign)	SD Date 28 Sep. 2010	Vessel	Shaaka!

Comments

Compass Cal - DOWN
Had to be re-set because of Memory Card being off of slot. Changed time start, reset memory.
Filename changed to 'PANDN001.000' when sent to Ambrozy by email (Sep 28th, 2010)

All fields must be completed. Circle or strikethrough options as appropriate.

DEPLOYMENT LOG

amec

RD Instruments Workhorse ADCP

Project No ~~TV01050~~ Client PWGSC / DFO
Location (Rig & Well Site) ~~Pangnirtung~~

Instrument Details

Model	(Sentinel) / ~~Long Ranger~~	Frequency	300 (kHz)	Instrument Serial No	3464
Firmware version	51.38	Memory size (MB)	(PC card 1) 1024 (PC card 2) —		
Depth rating (m)		Pressure sensor fitted	(Yes) / ~~No~~	Sensor depth rating (m)	
Comm. settings	RS232,9600,8,N,1	Comm. Settings (If different)	—		
New battery	(Yes) / No Voltage 44.6	External batteries (Quantity)	— Voltage —	Initials M.B	Date 3 Aug 10

PlanADCP	Variable		Result		Result
Command file name	Pangnirtung1.txt	First cell range	4.15 m	Power usage	579.65 wH
Water temperature	5 °C	Last cell range	132.15 m	Battery pack usage	1.3
Salinity	35 ppt	Maximum range	128.11 m		
Transducer depth	0 m	Standard Deviation	0.92 cm/sec		
Magnetic Declination	0 °	Ensemble size	256 Bytes		
Deployment duration	55 days	Storage space required	7.32 MB	Initials SD	Date 25-Aug-2010

Command Summary

CF	11101	Flow control	WD	111 00000	Data output (v,c,a,pg,st,p0,p1,p2,p3)
BM	—	Bottom Track mode	WF	176	Blank after transmit (cm)
BP	—	Bottom Track pings/ensemble	WN	65	Number of depth cells
BX	—	Maximum Tracking depth (dm)	WP	150	Water track pings/ensemble
EA	0	Heading alignment (1/100 th deg)	WS	200	Depth cell size (cm)
EB	0	Heading bias (1/100 th deg)	WV	175	Ambiguity velocity
ED	0	Transducer depth (dm)	TE	00:15:00.00	Time per ensemble (hh:mm:ss.ss)
ES	35	Salinity (ppt)	TP	00:00.60	Time per ping (mm:ss.ss)
EX	11111	Coordinate xform	TF	10/08/17 00:00:00	Time of first ping (yy/mm/dd,hh:mm:ss)
EZ	1111101	Sensor source (c,d,h,p,r,s,t)	CK	✓	Keep parameters as user defaults
WB	1	Mode 1 bandwidth control (0=wide, 1=narrow)	CS	✓	Start deployment
RN	—	Set deployment name (SMMYY: Site, Mo,Yr)			(Other commands)
WA	50	False Target Threshold			Initials SD Date 25-Aug-2010

Deployment

Deployed Orientation (Upward) / ~~Downward~~ Mode (Self-contained) / ~~Telemetry~~ (Note: If telemetry, complete 'Telemetry Log Sheet'.)
ADCP set to GMT Yes Memory erased ✓ Pinging confirmed YES
Water depth '147.24' m ~~Sounded~~ / Charted (CD) Instrument depth ~60 m
Coordinates (deg min.min) 377,562 E ; 7,341,144 N ⊕ ~40m NE Datum UTM zone 20 NAD83
Range/Bearing (from platform) — n.m. — ° True Magnetic Variation —
Instrument submerged (yy/mm/dd,hh:mm) 2010-08-25 19:45 EDT ~~GMT~~ 23:45 GMT Vessel Silver Dolphin III
Senior Tech. (sign) SD MB Date 25-Aug-2010

Recovery

Time out of water (yy/mm/dd,hh:mm) 10/09/28, 1401 EDT, (1801 GMT) Clock error None Found
Time turned off (yy/mm/dd,hh:mm) 10/09/16 01:00:00 GMT Data file name PANUP000.000
Senior Tech. (sign) SD Date 28-Sep-2010 Vessel Shaabal

Comments

Compass Cal - UP ~~PUP~~ Pon UP
Unit stoped on Sep 16th prematurely. Seem to be due to battery depletion
Was unable to comunicate with, downloaded data from PC card.

All fields must be completed. Circle or strikethrough options as appropriate.

APPENDIX B

Tide Gauges Harmonic Analysis Results

file name: TG1_tide.out
date: 24-Nov-2010
nobs = 8929, ngood = 8929, record length (days) = 31.00
start time: 28-Aug-2010
rayleigh criterion = 1.0
Greenwich phase computed with nodal corrections applied to amplitude and phase relative to center time

x0= 7.05, x trend= 0

var(x)= 3.0564 var(xp)= 3.0438 var(xres)= 0.012584
percent var predicted= 99.6 %

tidal amplitude and phase with 95% CI estimates

tide	freq	amp	amp_err	pha	pha_err	snr
MSF	0.00282	0.0236	0.004	287.62	8.37	45
2Q1	0.03571	0.0020	0.003	78.43	87.32	0.51
Q1	0.03722	0.0088	0.003	66.86	23.03	9.3
O1	0.03873	0.0535	0.003	80.64	3.20	2.9e+002
NO1	0.04027	0.0017	0.002	100.33	85.95	0.5
K1	0.04178	0.0571	0.004	110.22	3.43	2.5e+002
J1	0.04329	0.0077	0.003	114.28	24.77	5.8
OO1	0.04483	0.0045	0.003	77.54	36.93	2.9
UPS1	0.04634	0.0013	0.002	129.13	101.17	0.34
N2	0.07900	0.5137	0.003	261.41	0.40	2.2e+004
M2	0.08051	2.2063	0.003	287.78	0.08	4.6e+005
S2	0.08333	1.0440	0.003	327.96	0.19	1e+005
ETA2	0.08507	0.0304	0.003	33.87	5.94	1.2e+002
MO3	0.11924	0.0085	0.003	21.40	19.93	7.8
M3	0.12077	0.0227	0.004	78.56	10.58	41
MK3	0.12229	0.0097	0.003	303.30	22.17	8.5
SK3	0.12511	0.0086	0.003	24.72	22.74	7.5
MN4	0.15951	0.0127	0.003	103.18	17.45	17
M4	0.16102	0.0152	0.003	164.93	11.97	20
MS4	0.16384	0.0026	0.003	318.75	72.37	0.77
S4	0.16667	0.0037	0.003	155.93	59.28	1.2
2MK5	0.20280	0.0004	0.002	8.90	217.29	0.035
2SK5	0.20845	0.0013	0.003	3.06	125.70	0.24
2MN6	0.24002	0.0024	0.003	212.17	83.14	0.7
M6	0.24153	0.0037	0.003	247.06	51.56	1.3
2MS6	0.24436	0.0020	0.003	345.65	91.95	0.49
2SM6	0.24718	0.0007	0.002	277.03	176.61	0.084
3MK7	0.28331	0.0002	0.002	71.09	253.77	0.0096
M8	0.32205	0.0006	0.002	243.35	182.74	0.092

file name: TG2_tide.out
date: 24-Nov-2010
nobs = 8929, ngood = 8929, record length (days) = 31.00
start time: 28-Aug-2010
rayleigh criterion = 1.0
Greenwich phase computed with nodal corrections applied to amplitude and phase relative to center time

x0= 6.71, x trend= 0

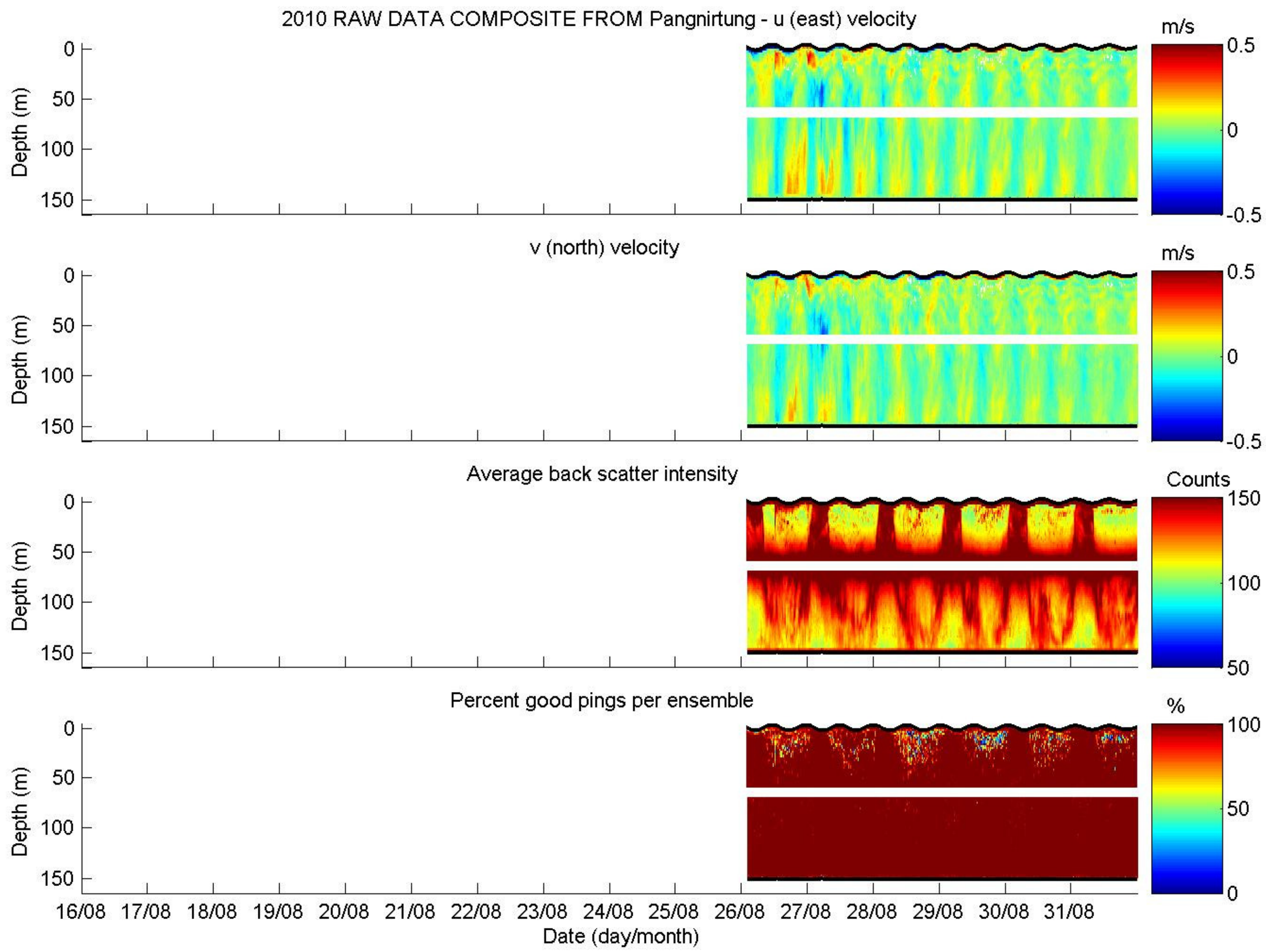
var(x)= 3.0153   var(xp)= 3.0028   var(xres)= 0.012476
percent var predicted= 99.6 %

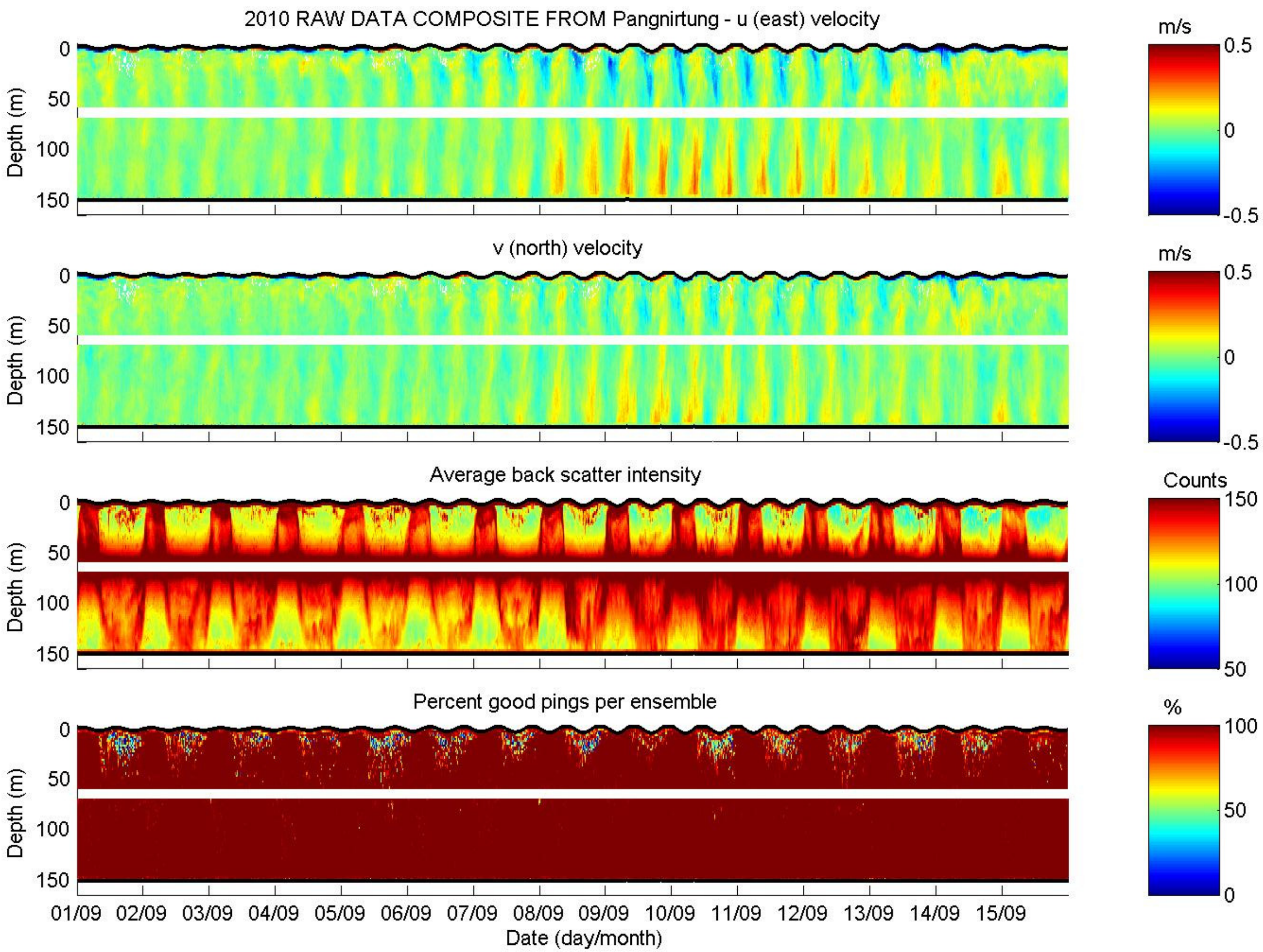
tidal amplitude and phase with 95% CI estimates

tide	freq	amp	amp_err	pha	pha_err	snr
MSF	0.00282	0.0219	0.003	281.18	9.19	44
2Q1	0.03571	0.0019	0.002	80.08	84.92	0.64
Q1	0.03722	0.0085	0.003	63.83	22.16	6.3
O1	0.03873	0.0531	0.003	80.21	3.64	3e+002
NO1	0.04027	0.0019	0.002	99.16	86.65	0.8
K1	0.04178	0.0575	0.004	109.66	3.00	2.5e+002
J1	0.04329	0.0078	0.004	111.91	22.82	4.9
OO1	0.04483	0.0047	0.003	79.59	32.53	3
UPS1	0.04634	0.0012	0.002	126.87	122.52	0.3
N2	0.07900	0.5112	0.003	261.29	0.41	2.9e+004
M2	0.08051	2.1920	0.003	287.54	0.09	3.9e+005
S2	0.08333	1.0352	0.003	327.66	0.18	9.8e+004
ETA2	0.08507	0.0296	0.003	33.24	5.89	94
MO3	0.11924	0.0087	0.003	19.63	20.84	6.6
M3	0.12077	0.0225	0.004	77.83	8.32	33
MK3	0.12229	0.0094	0.003	302.51	19.85	7.9
SK3	0.12511	0.0083	0.004	24.88	23.95	5.4
MN4	0.15951	0.0117	0.004	100.17	18.42	8.4
M4	0.16102	0.0131	0.004	159.70	13.64	13
MS4	0.16384	0.0030	0.003	349.06	73.12	0.85
S4	0.16667	0.0036	0.003	152.93	51.61	1.3
2MK5	0.20280	0.0005	0.002	340.44	219.97	0.039
2SK5	0.20845	0.0011	0.002	2.92	157.43	0.22
2MN6	0.24002	0.0022	0.003	197.84	95.98	0.58
M6	0.24153	0.0032	0.004	234.68	80.57	0.83
2MS6	0.24436	0.0013	0.003	324.16	133.18	0.26
2SM6	0.24718	0.0007	0.002	270.27	176.19	0.099
3MK7	0.28331	0.0001	0.002	94.25	252.91	0.0038
M8	0.32205	0.0000	0.002	302.22	277.08	0.00046

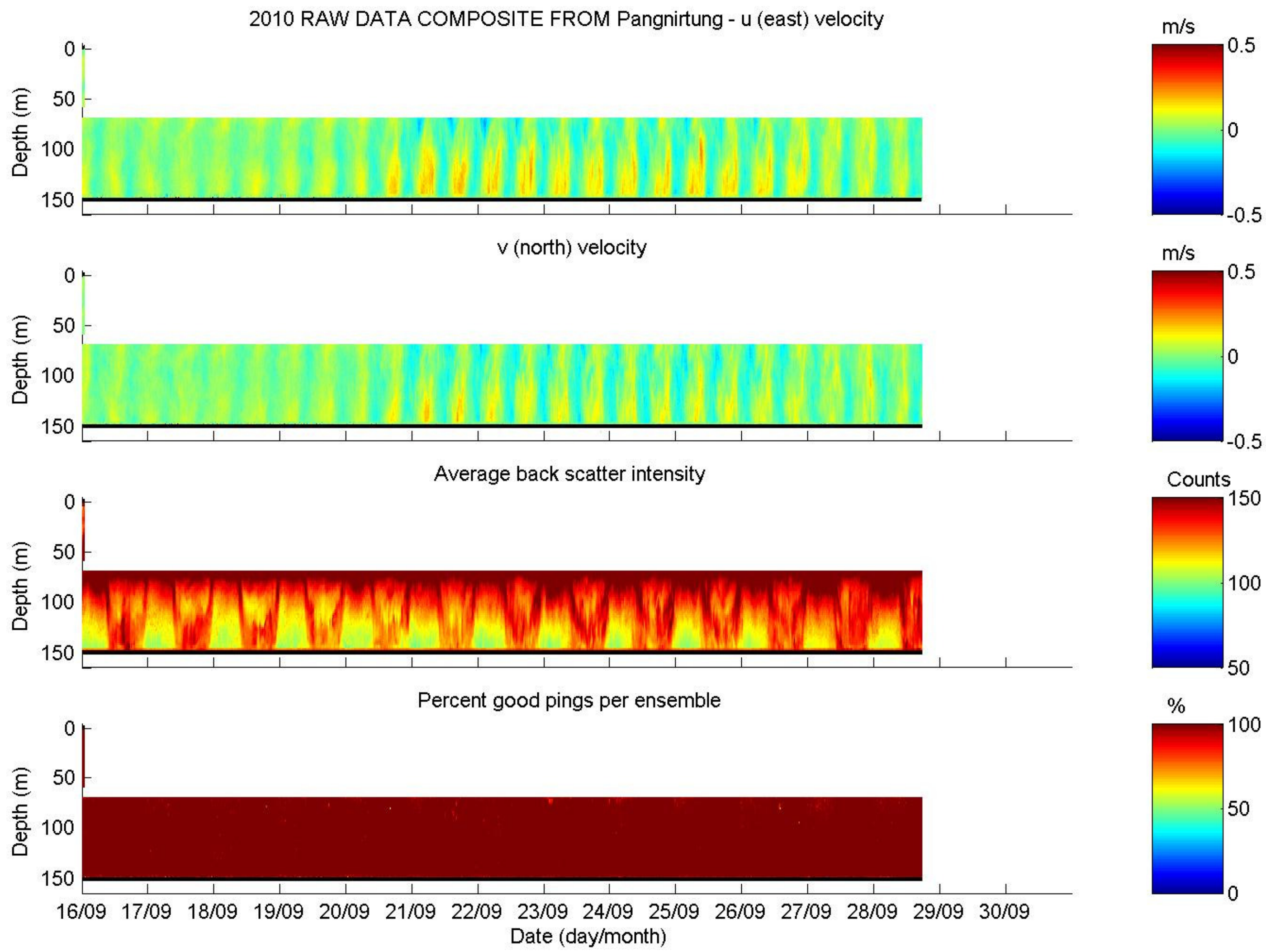
APPENDIX C

ADCPs Data Results


2010 RAW DATA COMPOSITE FROM Pangnirtung - u (east) velocity
v (north) velocity
Average back scatter intensity
Percent good pings per ensemble
Depth (m)
0
50
100
150
m/s
0.5
0
-0.5
Counts
150
100
50
%
100
50
0
16/08
17/08
18/08
19/08
20/08
21/08
22/08
23/08
24/08
25/08
26/08
27/08
28/08
29/08
30/08
31/08
Date (day/month)



2010 RAW DATA COMPOSITE FROM Pangnirtung - u (east) velocity
v (north) velocity
Average back scatter intensity
Percent good pings per ensemble
Depth (m)
0
50
100
150
01/09
02/09
03/09
04/09
05/09
06/09
07/09
08/09
09/09
10/09
11/09
12/09
13/09
14/09
15/09
Date (day/month)
m/s
0.5
0
-0.5
Counts
150
100
50
%


2010 RAW DATA COMPOSITE FROM Pangnirtung - u (east) velocity
v (north) velocity
Average back scatter intensity
Percent good pings per ensemble
Depth (m)
0
50
100
150
16/09
17/09
18/09
19/09
20/09
21/09
22/09
23/09
24/09
25/09
26/09
27/09
28/09
29/09
30/09
Date (day/month)
m/s
0.5
0
-0.5
Counts
150
100
50
%
100
50
0

APPENDIX D

ADCPs Harmonic Analysis Results

file name: PangnirtungUP_238.0833_259.0417_7_59.tide.out
date: 04-Nov-2010
nobs = 2014, ngood = 2013, record length (days) = 20.98
start time: 26-Aug-2010 02:00:00
rayleigh criterion = 1.0
Greenwich phase computed with nodal corrections applied to amplitude and phase relative to center time

x0= -0.174, x trend= 0

var(x)= 2943.7318 var(xp)= 2243.9634 var(xres)= 699.7684
percent var predicted= 76.2 %

y0= 4.52, y trend= 0

var(y)= 1679.9171 var(yp)= 1245.7682 var(yres)= 434.1489
percent var predicted= 74.2 %

ellipse parameters with 95%% CI estimates

tide	freq	major	emaj	minor	emin	inc	einc	pha	epha	snr
MSF	0.00282	20.879	1.796	-1.075	1.00	18.94	3.01	193.23	5.23	1.4e+02
O1	0.03873	1.899	1.317	1.275	1.03	24.60	68.60	345.63	88.44	2.1
K1	0.04178	4.830	1.912	0.234	0.97	16.21	11.76	53.56	19.81	6.4
N2	0.07900	7.883	2.125	-0.322	0.89	37.38	7.44	159.47	14.15	14
M2	0.08051	69.088	1.928	-2.819	0.98	37.38	0.80	216.27	1.55	1.3e+03
L2	0.08202	14.742	2.659	-0.602	1.26	37.38	5.09	220.05	9.92	31
S2	0.08333	32.642	1.873	-2.586	0.87	39.52	1.86	262.80	3.64	3e+02
M3	0.12077	2.000	1.381	-1.159	1.26	163.06	71.94	170.20	80.72	2.1
SK3	0.12511	1.496	1.329	0.717	1.08	11.10	49.19	305.05	89.80	1.3
M4	0.16102	3.399	1.216	1.330	1.76	153.63	36.68	180.61	29.91	7.8
MS4	0.16384	3.566	1.511	1.660	1.60	159.58	38.11	165.40	33.47	5.6
S4	0.16667	3.467	1.062	-0.275	1.79	132.87	34.38	210.05	18.49	11
2MK5	0.20280	1.139	1.356	-0.655	1.00	56.96	64.66	140.24	107.69	0.71
2SK5	0.20845	1.060	1.010	-0.337	1.33	103.06	106.07	175.68	77.77	1.1
M6	0.24153	3.691	1.191	-0.436	1.77	142.87	26.94	336.41	18.61	9.6
2MS6	0.24436	2.897	1.015	-1.531	1.76	116.39	64.07	299.09	39.39	8.1
2SM6	0.24718	3.148	1.283	-1.474	1.52	159.07	40.15	323.77	37.63	6
3MK7	0.28331	1.125	1.132	-0.497	1.11	96.50	114.28	226.41	78.79	0.99
M8	0.32205	2.440	1.130	-0.456	1.61	107.45	47.56	242.29	35.51	4.7

total var= 4623.6488 pred var= 3489.7315
percent total var predicted= 75.5 %

file name: PangnirtungDN_238.0833_271.7083_69_133.tide.out
date: 04-Nov-2010
nobs = 3231, ngood = 3231, record length (days) = 33.66
start time: 26-Aug-2010 02:00:00
rayleigh criterion = 1.0
Greenwich phase computed with nodal corrections applied to amplitude and phase relative to center time

x0= 8.47, x trend= 0

var(x)= 2862.4367 var(xp)= 2460.8681 var(xres)= 401.5686
percent var predicted= 86.0 %

y0= -2.8, y trend= 0

var(y)= 1996.8425 var(yp)= 1773.3696 var(yres)= 223.4729
percent var predicted= 88.8 %

ellipse parameters with 95%% CI estimates

tide	freq	major	emaj	minor	emin	inc	einc	pha	epha	snr
MM	0.00151	20.012	1.008	1.287	0.77	45.87	2.04	40.93	3.43	3.9e+02
MSF	0.00282	7.856	1.056	2.691	0.60	18.33	6.29	48.12	10.81	55
ALP1	0.03440	1.660	1.076	0.135	0.55	35.58	20.85	168.77	37.81	2.4
2Q1	0.03571	0.940	0.861	0.457	0.54	17.50	54.76	129.15	82.68	1.2
Q1	0.03722	2.202	1.180	0.277	0.53	32.72	14.59	249.84	28.83	3.5
O1	0.03873	2.278	1.040	0.406	0.63	33.77	17.88	294.22	29.75	4.8
NO1	0.04027	1.703	0.818	0.236	0.44	34.23	15.45	15.66	24.91	4.3
K1	0.04178	2.059	0.980	0.318	0.62	3.07	22.00	293.50	26.26	4.4
J1	0.04329	3.300	1.062	0.098	0.72	54.04	10.86	49.90	18.93	9.7
OO1	0.04483	1.580	0.780	0.343	0.44	25.92	18.07	116.69	32.41	4.1
UPS1	0.04634	0.682	0.792	-0.035	0.43	36.82	34.19	28.54	73.94	0.74
EPS2	0.07618	3.780	1.016	-0.142	0.61	22.36	8.54	150.33	18.72	14
MU2	0.07769	6.733	1.053	-1.062	0.60	22.33	5.04	193.39	9.48	41
N2	0.07900	8.264	1.133	1.496	0.52	20.33	4.87	137.56	8.29	53
M2	0.08051	76.422	1.312	5.178	0.56	39.96	0.47	194.36	0.83	3.4e+03
L2	0.08202	15.454	1.293	1.168	0.86	48.91	3.24	198.14	5.52	1.4e+02
S2	0.08333	33.646	1.147	-0.491	0.64	40.07	1.10	230.36	1.87	8.6e+02
ETA2	0.08507	3.590	0.947	0.068	0.60	53.17	10.29	64.28	13.69	14
MO3	0.11924	1.682	0.651	0.091	1.11	108.19	43.78	340.48	24.51	6.7
M3	0.12077	1.476	0.805	-0.639	0.85	62.33	38.29	17.61	54.68	3.4
MK3	0.12229	1.144	0.956	0.237	0.69	175.94	52.32	73.39	60.15	1.4
SK3	0.12511	1.834	1.124	0.120	0.59	36.66	18.46	308.09	37.22	2.7
MN4	0.15951	6.289	1.225	-1.024	0.67	35.31	6.04	6.36	10.37	26
M4	0.16102	12.220	1.101	-2.118	0.66	28.15	3.32	131.55	5.62	1.2e+02
SN4	0.16233	1.518	0.635	-0.096	0.97	100.93	46.49	337.87	30.98	5.7
MS4	0.16384	9.405	1.249	-1.057	0.59	29.60	4.16	176.35	6.80	57
S4	0.16667	2.484	0.712	-0.591	1.09	142.29	28.08	56.98	18.24	12
2MK5	0.20280	1.609	0.642	-1.180	0.87	147.89	72.65	261.99	63.60	6.3
2SK5	0.20845	0.734	0.650	-0.095	0.82	89.47	84.59	30.90	69.18	1.3
2MN6	0.24002	2.158	1.171	-0.828	0.69	13.78	23.54	269.49	33.89	3.4
M6	0.24153	2.662	0.792	-1.790	0.88	153.51	44.64	204.41	41.13	11
2MS6	0.24436	2.334	0.620	-1.217	1.09	118.34	39.56	267.23	27.11	14
2SM6	0.24718	1.572	0.825	-0.151	0.96	88.73	38.76	342.89	30.10	3.6
3MK7	0.28331	0.907	0.756	-0.233	0.80	153.17	73.19	19.39	65.63	1.4
M8	0.32205	2.225	0.927	-1.494	0.72	67.36	48.31	159.76	48.29	5.8

total var= 4859.2792 pred var= 4234.2376
percent total var predicted= 87.1 %