Spatial and temporal observations of fish waste at a discontinued aquaculture site Lake Huron, North Channel, Ontario.

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Abstract

Our study site is a discontinued caged-aquaculture farm located in the North Channel near Manitoulin Island Ontario. We sampled the site once a year from 2000 to 2007. We analyzed samples for pore water ammonia and % Loss on Ignition to determine the spatial extent of the fish waste deposit and determined the temporal decrease in fish waste using underwater video. We found that the fish deposit was confined to 15 m from the pre-existing cages. This study has demonstrated that approximately 9 years were required for the particulate waste deposit to disperse and/or be assimilated at this site.

Introduction

Aquaculture is one of the fastest growing food producing industries in the world. In Canada, there were 6,598 licensed operations in 2004 (Department of Fisheries and Oceans 2007). Aquaculture is practiced in every province including the Yukon Territory. In Ontario, the Great Lakes provide a potential opportunity for growth in the fresh water sector, however, the possibility of environmental impacts are influencing further expansions of the industry in Ontario (Moccia and Hynes 1998). In the Great Lakes region all cage-aquaculture is currently practiced in Lake Huron and Georgian Bay. The need for sustainable environmental management of cage-aquaculture farms is of utmost importance to preserve the ecological integrity of the Great Lakes. The environmental concerns include, but are not limited to, the impact of farming activities on water quality, benthic communities (excess feed and feces) and native fisheries (Axler et al. 1996; Axler et al. 1996; Brooks et al. 2003; Brown et al. 1987). Industry, regulators, academic and other government agencies are striving to create a sustainable ecosystem approach.

Solid fish waste is an integral part of freshwater caged-aquaculture. Solid waste includes fish feces and fish food. Generally, fish waste is deposited directly under or within a radius of 20 to 50 m of the cages (Brown et al. 1987; Pereira et al. 2004; Karakassis et al. 1999). Build up of fish waste can potentially impact benthos, water quality and dissolved oxygen affecting the environment and farm operations. Currently, it is unknown to what degree sediment recovery occurs after cessation of farming operations or how present environmental conditions control such recoveries in the Great Lakes. This information is important for regulatory agencies in making sound decisions regarding remediation or mitigation of each site in question. The objectives of the following study were to determine the extent of the depositional area of fish waste using pore water ammonia and % Loss on Ignition (LOI) as well as assess the spatial and temporal decrease in fish waste using underwater video at a discontinued freshwater caged-aquaculture site in Ontario. It should be noted that no other analyses were completed in this study. This study was for preliminary observational purposes only.

Methods

The area of study is a discontinued aquaculture site located approximately 10 km north of Little Current on Great La Cloche Island near Grassy Bay (fig.1). The farm operated from 1993 to 1999 and consisted of eight 15mx15m cages with a total production of approximately 400,000 lbs of rainbow trout annually. The site was sampled once a year beginning in March 2000 until February 2007. Total depths ranged from approximately 12m to 20 m.

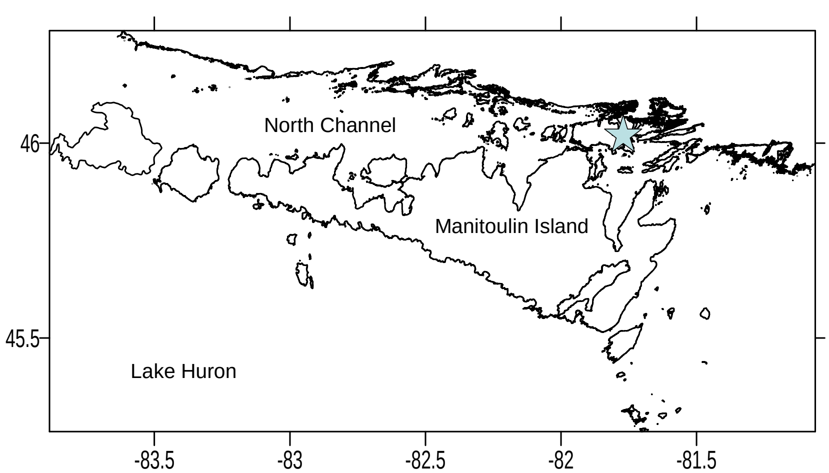


Fig. #1

Fig. 1 The study site is located approximately 10 km north of Little Current on Great La Cloche Island near Grassy Bay.

The study was completed during thick ice cover where sampling could be completed accurately and efficiently. Upon arrival at the site, a base station was set up to acquire Differential Global Positioning System (DGPS) coordinates (appendix 1). Once completed, a sampling grid was laid out on the ice identifying stations approximately 5 m apart. After the stations were determined, holes were drilled through the ice using a 12 inch ice auger. Fifteen transects labeled D to R with up to 14 stations in each transect were sampled. A control station NW-2 (fig. 2) was located approximately 1.5 km NW of the site.

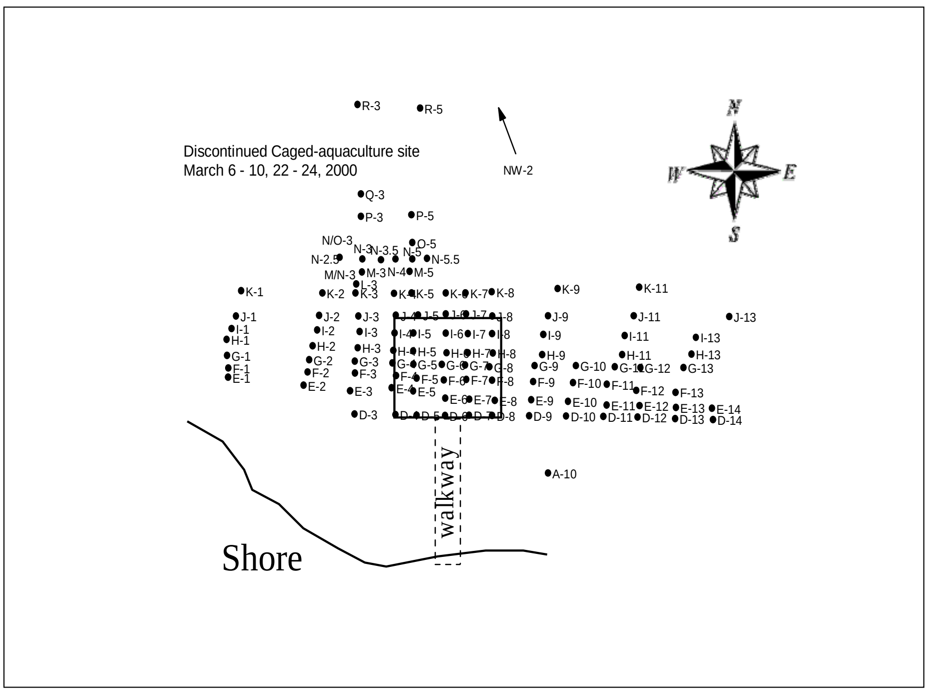


Fig. 2 One hundred and twelve stations were sampled at a discontinued caged-aquaculture farm in 2000.

In total, 112, 41, 51, 39, 50, 51 and 48 stations were sampled in 2000, 2002, 2003, 2004, 2005 2006 and 2007 respectively. Repeated attempts of sampling sediment occurred every year at 25 stations located directly under the pre-existing cage site (Fig. 3).

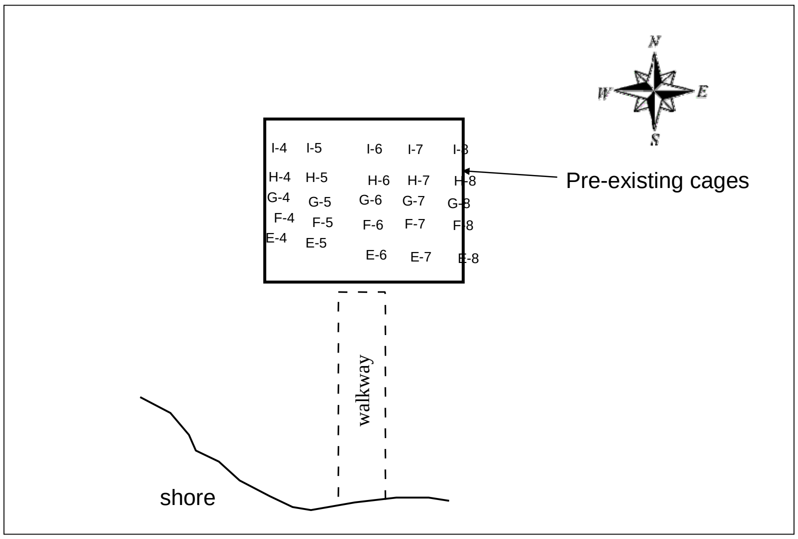


Fig. 3 Attempts at sampling under the pre-exiting cage site was repeated at 25 stations every year of the study.

No samples were collected in 2001 since DGPS signal was not acquired and stations positions could not be accurately determined. In 2000, several cores were attempted below the pre-existing fish cages with a Technical Operations corer but were unsuccessful due to the flocculent nature of the sediment. Collection of 1 core was successful using a light weight corer in 2000. Ekman and PONAR grabs were utilized where collection of cores were unsuccessful. Sediment from grab samples were homogenized, sub-sampled and placed in sealable plastic bags and stored in coolers. In 2000, the stations were chosen inside and outside the boundary of the pre-existing fish cages to determine the depositional area or “foot print” of the farming operation. Fish feces were identified from background sediment by odour, colour and consistency and in 2000 to 2004 by ammonia concentration and in 2000 and 2002 by % Loss on Ignition (LOI) or carbon content. This is a semi-quantitative method that provides a good indication of the organic content and a rough estimate of total organic carbon of each core section (Beaudoin 2003; Santisteban et al. 2004; Schumacher 2002). Lake sediments typically have lower pore water ammonia and % LOI than areas exposed to excess organic enrichment (Beaudoin 2003; Santisteban et al. 2004; Schumacher 2002). % LOI alone, however, may not be a good indicator of fecal material, because % LOI does not discriminate from other sources of organic enrichment (Tlusty et al. 2000). However, in conjunction with pore water ammonia analyses % LOI can provide a reasonable estimate of organic input from farming activities. From 2002 to 2007 video surveys of the lake bottom and sediment deposit thickness were conducted using an underwater video camera (Deep Blue Pro SplashCam™) attached to a pole marked in 10 cm increments, hereafter known as a penetrometer. The penetrometer was lowered to the sediment water interface then slowly lowered into the sediment. This system worked well because of a predominantly rock substrate. When the penetrometer could no longer be lowered, the depth of sediment (fish waste) was determined by counting 10 cm increments on the pole attached to the camera, providing a reasonably good estimate of the depth of deposit. All camera work was recorded for further detailed observation.

Laboratory Analyses

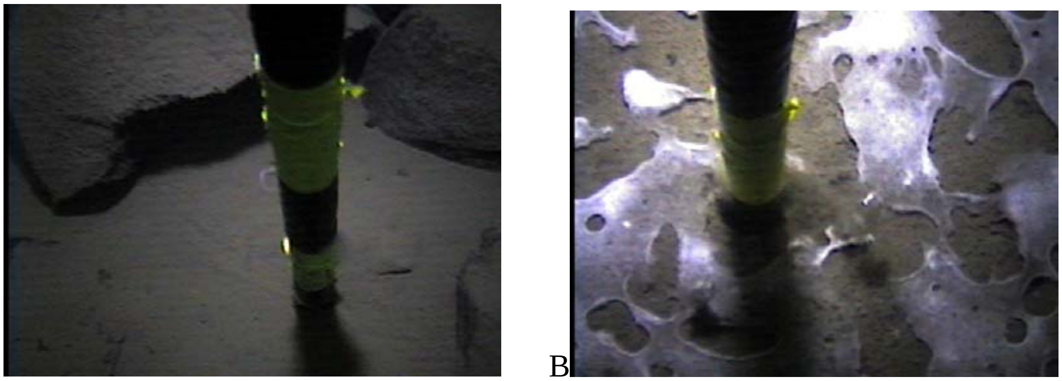
On return from the field sub-sampled sediment from grab samples were centrifuged at 3800 RPM for 20 minutes in the laboratory. The pore water was then extracted and the ammonia was measured using a Thermo Orion electrode. Once the pore water ammonia analyses were complete, the remaining sediment was then freeze dried, pulverized, and fired at 500°C for 2 hours to determine the % LOI.

Statistical Analyses

An ANOVA was implemented to determine significant differences of the fish waste deposit between the years. A linear regression was applied to predict the year in which the fish waste deposit would be completely dispersed and/or assimilated.

Results

The greatest depositional area was typically limited to within 15 m of the pre-existing cage area. Areas beyond 15 m from pre-existing cages were predominantly rock and cobble; therefore no sediment could be collected (fig. 4). *Beggiatoa* spp. is a white filamentous mat of bacteria often associated with sulfide rich sediments (Kamp et al. 2006; Sweerts et al. 1990). While white mats were observed on the sediment at our study site it was not confirmed as *Beggiatoa* spp (Fig.4), however, seemed to be associated with fish waste.



A B

Fig. 4 (A) illustrates the penetrometer resting on bedrock where rock and cobble were the predominant substrate >15m from the pre-existing cage site. (B) illustrates the penetrometer resting in the fish waste deposit. The white mat associated with the fish waste deposit in (B) is potentially *Beggiatoa* spp, however, this was not confirmed. The fish waste deposit was localized within 15 m of pre-existing cages.

The average pore water ammonia in 2000 directly under the pre-existing cage areas was 98 mg/L, whereas approximately 15 m east and west the average pore water ammonia was 18 mg/L. No pore water ammonia was observed >15m from the site. The average pore water ammonia at the control site was 1 mg/L. Pore water ammonia decreased 33 % between 2000 and 2002 (98 mg/L and 66 mg/L); 32% between 2002 and 2003 (66 mg/L and 45 mg/L); although the results were not significantly different between years. The average % LOI directly under the pre-existing cage areas in 2000 were 53% and 10 m east and west of the pre-existing cages were on average 19% whereas the % LOI at the control site was 13%. The average % LOI did not vary between 2000 and 2002 (53% and 51%). Table 2 shows the average results for pore water ammonia, % LOI and deposit depth from 2000 to 2007. The averages were based on stations located under the pre-existing cages for all years.

Table 2. Pore water ammonia, % Loss on Ignition and depth of deposit averages directly under pre-existing cages between 2000 and 2007.

Year	2000	2002	2003	2004	2005	2006	2007
Ammonia in pore water (mg/L)	**98** n=20	**66** n=9	**45** n=3	N/A	N/A	N/A	N/A
% LOI	**53** n=16	**51** n=9	N/A	N/A	N/A	N/A	N/A
Depth of deposit (penetrometer) (cm)	N/A	**20** n=25	**18** n=25	**13** n=25	**10** n=25	**8** n=25	**9** n=25

In 2000, the depth of waste deposits was approximately 100 cm; however, this observation was based on 1 core sample collected directly under pre-existing cages. No other cores were collected. On average, the deposit depth decreased 3.3 cm/year between 2002 and 2006; however, based on an ANOVA no significant differences were evident between the years. A significant difference, however, was evident between 2002 and 2005 as well as between 2006 and 2007. In 2002, when video assessments began, the average depth of deposits was 20 cm. In 2007, the average depth of the deposit decreased to 8 cm. By implementing a simple regression, the deposit is predicted to have completely disappeared by mid 2008. However, in 2007 a slight increase of sediment depth was observed (-0.7 cm/year) (Fig. 5).

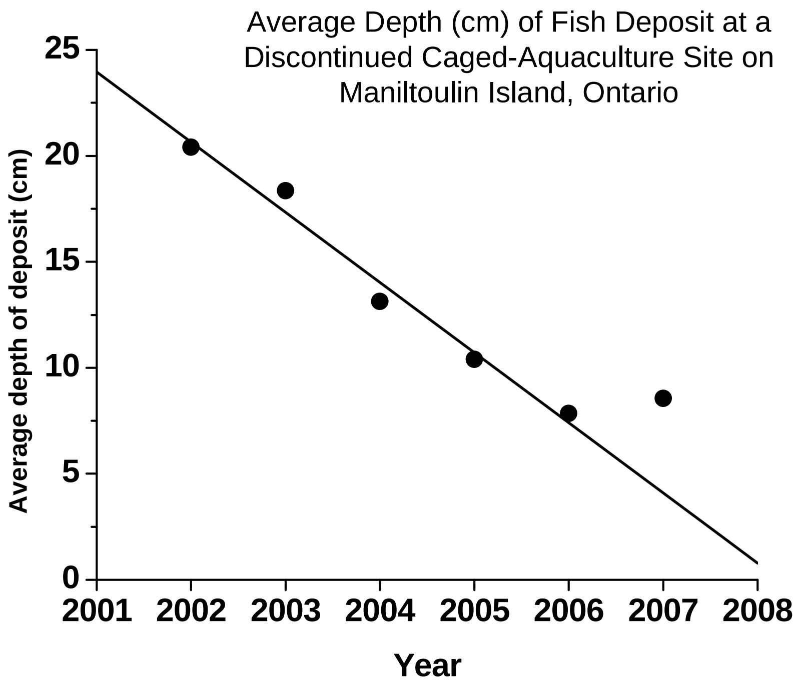


Fig. 5 The average depth of fish deposit decreased 3.3 cm/year from 2002 to 2006. In 2007 the depletion rate was 2 cm/year y = -3.3098x + 6646.9 R^2 = 0.9804 .

Discussion

Currently in Ontario, the time required for site remediation after cessation of farming operations is largely unknown. Most studies on sediment remediation have been for mariculture management (Macleod et al. 2002; Macleod et al. 2004; Macleod et al. 2006; Karakassis et al. 1999; McGhie et al. 1998; Axler et al. 1998; Brooks et al. 2004; Pereira et al. 2004). There have been many different approaches to define evidence of site remediation including analyses of organic nitrogen and carbon, lipids, % Loss on Ignition, sediment redox, sulfide concentrations and video assessments. However, descriptions of benthic fauna are the most reliable indicators of sediment remediation (Macleod et al. 2004). This technique can be costly and time consuming. In this preliminary study analyses of pore water ammonia, % Loss on Ignition and video assessments were chosen because all are simple and cost effective.

Fish deposits from caged-aquaculture farm operations potentially alter benthic communities (Axler et al 1996), increase nutrient concentrations (Folke and Kautsky 1989), and cause anoxic conditions (Cornel and Whoriskey 1993). Solid fish waste, which include fish feces and uneaten fish feed, is an integral part of freshwater caged-aquaculture. Sedimentation rates under a working farm can be up to 20 times higher than background (Folke and Kautsky 1989), therefore site selection is important to both farming operations and ecosystem integrity and will influence the ability for sites to fully recover after cessation of farming.

The time required for sediment remediation can vary considerably. Ritz et al. 1989 reported benthic faunal recovery in 7 weeks at a seafarm in Tasmania, whereas, some marine caged-aquaculture sites show that remediation of benthic fauna begins during harvest of fish and returns to a background state within 5 to 6 months post harvest, for example, at a mariculture farm off the west coast of Canada (US Department of Commerce and National Oceanic and Atmospheric Administration 2001); (Brooks et al. 2004). Similar results were observed for levels of hydrogen sulfide, ammonia, dissolved oxygen and zinc (Brooks et al. 2004) . Freshwater remediation has been observed at a mine pit lake in Minnesota after intense aquaculture farming for 7 years (Axler et al, 1998). After 18 months post-productivity, phosphorus in water and dissolved oxygen concentrations returned to reference levels. Results from our study show that the dispersion/assimilation rate is 3.3 cm/year from 2000 until 2006, at this site. While in 2007 sediment accumulation appeared to occur, we believe the bottom topography beneath the pre-exiting cages consists of small depressions where fish deposit movement is restricted; therefore these areas consistently have a deposit depth greater than the surrounding area. Similar results were reported by Tlusty et al. 2000, where in Bay d'Espoir, Canada, found large differences in % LOI between samples in close proximity suggesting bottom topography may create pockets of localized accumulation.

Water depth, settling velocities of organic matter, current speeds (Gowen and Bradbury 1987), basin morphometry, and sediment characteristics can greatly effect the dispersion and/or assimilation of fish waste. Proper site selection for a caged-aquaculture operation is important for the integrity of the ecosystem, farming operations, and site rehabilitation after farm operations have ceased.

The Ontario Ministry of Environment (OMOE) has classified farm sites into 3 categories to reduce water quality impairment caused by farming operations. Type 1 sites are enclosed (lake-like) basins with limited flushing. Type 2 sites are partially exposed, having good epilimnion/metalimnion flushing rates but limited or no hypolimnion exchange. Type 3 sites are exposed locations where the hypolimnion is also well flushed (Boyd et al. 2001). Farms in Type 1 sites generally result in deleterious conditions in the receiving waters because of low flushing rates (Axler et al. 1996; Axler et al. 1998a; Clerk et al. 2004) and result in a potential increase of fish waste directly under the cages and associated prolonged recovery time, whereas Type 3 sites seem to support farming operations with very little measurable effects (Cromey et al. 2002). These sites tend to be located in more dynamic environments where waste particulates are dispersed away from the cages and may result in decreased recovery time. Type 2 sites may or may not be suitable for farming operations depending on, for example, the surrounding land use, basin morphometry, total depth, currents, and sediment characteristics; for these sites, more extensive research and modeling is needed to determine the extent of waste deposits and recovery times.

Such information is important for regulators to assess environmental conditions for decommissioning a sight once aquaculture activities have terminated.

Conclusion

We analyzed pore water ammonia and calculated % Loss on Ignition to determine the "footprint" of the particulate fish waste. Most of the deposits were located within 15 m of the pre-existing fish cages. The depth of the deposits were assessed by inserting a camera mounted pole marked in 10 cm increments into the deposit. The substrate was predominantly rock, therefore a reasonably good estimate of the depth of the deposit could be determined. This study has shown it takes approximately 9 years for the particulate waste deposit to disperse and /or assimilate at this site. In 2000, the depth of the deposit was approximately 100 cm whereas, in 2007, it decreased to an average of 8 cm. This is a preliminary observational study of particulate waste deposits at a discontinued aquaculture site in Ontario. Future studies should include a benthic invertebrate, sulfide concentrations and a sediment redox component to more accurately determine the spatial and temporal changes in waste deposits at discontinued aquaculture sites in the Great Lakes.

Acknowledgements

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Appendix 1. Sampling positions at a discontinued aquaculture site in Ontario, 2000.

Station ID	Easting	Northing	Station ID	Easting	Northing
A-10	439318.3	5096440.5	**H-1**	439198.4	5096506.6
D-3	439246.1	5096469.6	**H-2**	439230.5	5096503.5
D-4	439261.4	5096469.3	**H-3**	439247.3	5096502.4
D-5	439269.3	5096469.1	**H-4**	439260.6	5096501.1
D-6	439279.9	5096468.9	**H-5**	439268	5096500.9
D-7	439288.8	5096469.1	**H-6**	439280.4	5096500
D-8	439297.4	5096468.9	**H-7**	439288.4	5096500
D-9	439311.3	5096468.8	**H-8**	439297.7	5096499.8
D-10	439325	5096468.6	**H-9**	439316.1	5096499.1
D-11	439338.9	5096468.5	**H-11**	439345.9	5096499.1
D-12	439351.7	5096468.2	**H-13**	439371.8	5096499.3
D-13	439365.7	5096467.4	**I-1**	439200.3	5096512
D-14	439379.8	5096466.9	**I-2**	439232.2	5096511.3
E-1	439199	5096487.9	**I-3**	439248.1	5096510.5
E-2	439227.1	5096484	**I-4**	439261.1	5096509.8
E-3	439244.5	5096481.2	**I-5**	439268.1	5096509.8
E-4	439260	5096482.6	**I-6**	439280.2	5096509.7
E-5	439268	5096481	**I-7**	439288.4	5096509.6
E-6	439280	5096477.4	**I-8**	439297.4	5096509.5
E-7	439288.9	5096477	**I-9**	439316.5	5096509.1
E-8	439298.4	5096476.4	**I-11**	439346.9	5096508.6
E-9	439312	5096476.8	**I-13**	439373.4	5096507.7
E-10	439325.7	5096475.8	**J-1**	439201.9	5096518.2
E-11	439340.1	5096474.1	**J-2**	439232.9	5096518.5
E-12	439352.4	5096473.8	**J-3**	439247.6	5096518.3
E-13	439366	5096473	**J-4**	439261.5	5096518.7
E-14	439379.4	5096472.6	**J-5**	439269.8	5096518.8
F-1	439199.1	5096492.5	**J-6**	439280.2	5096519.3
F-2	439228.6	5096490.5	**J-7**	439287.7	5096519.2
F-3	439246.3	5096490	**J-8**	439297.5	5096518.2
F-4	439261.6	5096488.7	**J-9**	439318.3	5096518.4
F-5	439269.3	5096487.4	**J-11**	439350.3	5096518.4
F-6	439279.4	5096486.5	**J-13**	439385.9	5096517.9
F-7	439287.8	5096486.9	**K-1**	439203.9	5096530.8
F-8	439297.4	5096486.4	**K-2**	439234.1	5096529.6
F-9	439312.7	5096485.7	**K-3**	439246.5	5096529.6
F-10	439327.6	5096485.3	**K-4**	439260.9	5096529.5
F-11	439340.2	5096484.4	**K-5**	439267.4	5096529.6
F-12	439351.2	5096481.4	**K-6**	439280.2	5096529.7
F-13	439365.9	5096480.4	**K-7**	439287.5	5096529.6
G-1	439198.6	5096498.7	**K-8**	439297.3	5096530.3
G-2	439229.2	5096496.6	**K-9**	439321.9	5096531.8
G-3	439246.2	5096495.8	**K-11**	439352.3	5096532.6
G-4	439260.2	5096495	**L-3**	439246.8	5096534.1
G-5	439268.1	5096494.4	**M-3**	439248.9	5096540
G-6	439278.7	5096494.3	**M-5**	439266.7	5096540.3
G-7	439287.4	5096494	**N2.5**	439240.6	5096547.3
G-8	439296.4	5096493	**N3**	439249.1	5096546.6
G-9	439313.3	5096493.7	**N3.5**	439256	5096546.1
G-10	439328.7	5096493.7	**N4**	439261.4	5096546.5
G-11	439343.2	5096493	**N5**	439267.7	5096546.6
G-12	439352.8	5096492.7	**N-5.5**	439273.2	5096546.8
G-13	439368.8	5096492.6	**O-3**	439248.2	5096555
			O-5	439267.7	5096554.6
			P-3	439248.5	5096567.7
			P-5	439267.3	5096568.4
			Q-3	439248.5	5096578.8
			R-3	439247.2	5096623
			R-5	439270.6	5096621.3
			M/N-3	439246.5	5096543
			N/O-3	439245	5096550
			NW-2	439551.8	5097912

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