Final Report

Manitoba Conservation and Water Stewardship

Review of the City of Winnipeg Response to a Process Failure at the South End Wastewater Pollution Control Center

October 2012

Executive Summary

In the latter part of 2011 the City of Winnipeg experienced a major upset with the biological (secondary) treatment process at the South End Wastewater Pollution Control Centre (SEWPCC). The main consequence was the discharge of effluent to the Red River, over an extended period, which did not comply with the requirements of the *Environment Act* License No. 2716 R that applies to this facility. Subsequently, Manitoba Conservation and Water Stewardship retained Associated Engineering to conduct a review with the following broad objective:

> *The objective of this project is to review all the technical and supporting information supplied by Manitoba Conservation and Water Stewardship and to diagnose and evaluate the systems, processes and procedures in place with the South End Wastewater Pollution Control Center itself and the City of Winnipeg Water and Waste Department as it relates to the South End Plant, and to make recommendations of potential changes or corrective actions that would prevent a similar occurrence and/or mitigate the impact of a similar occurrence.*

Based on our review of information provided, it is our opinion that the upset that began in early October 2011 was a filamentous bulking event that ultimately led to a significant compromise in final effluent quality over an extended period. Of the four potential event triggers presented, Condition 1, low bioreactor dissolved oxygen (DO) levels, appears to be the most likely event trigger. However, gaps in available information make it difficult to fully understand the events of early October 2011 that led to triggering of the filamentous bulking event and, as a result, the exact cause of this supposed trigger is unclear but likely involves a combination of factors. For a variety of technical reasons, and in the absence of any specific data to suggest otherwise, we believe it unlikely that the October event was the result of toxicant(s) discharge to the City wastewater collection system.

In general, the technical actions taken by the City in response to this event appear to have been appropriate given its probable underlying cause. However, the timeline of these actions suggested some inefficiency in the use of time in responding to the event. This likely contributed to the duration, and possibly the extent, of final effluent non-compliance. The City also appears to have made several choices, in terms of regular monitoring at the SEWPCC as part of normal facility operations, which may have compromised its ability to recognize, and thus respond quickly to, a developing bulking event. These findings illuminated a variety of deficiencies, or gaps, in City systems, protocols and infrastructure. Moving forward, the City can utilize the experience and knowledge gained during the course of the event to address these gaps.

Information made available for this review in terms of existing protocols and procedures, which were largely non-technical with a communications focus, indicated the City did appear to adhere to their general intent in specific instances. Our analysis was constrained by the extent of available material and, as a result, this conclusion cannot be further extended.

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List of Acronyms

ASB	Analytical Services Branch
CEMSM	Consolidated Environmental Management System Manual
CEPT	chemically-enhanced primary treatment
CERP	Consolidated Emergency Response Plan
DO	dissolved oxygen
HPOAS	high-purity oxygen activated sludge
MC	Manitoba Conservation and Water Stewardship
ML	mixed liquor
MLSS	mixed liquor suspended solids
ML/d	mega litres per day
NaOCl	sodium hypochlorite
NEWPCC	North End Wastewater Pollution Control Centre
OUR	oxygen uptake rate
PE	primary effluent
PFD	process flow diagram
PLF	process loading factor
PS	primary sludge
PSA	pressure swing absorption
Qww	wastewater flow
RAS	return activated sludge
SEWPCC	South End Wastewater Pollution Control Centre
SRT	solids retention time
SOP	standard operating procedure
SVI	sludge volume index
TBOD	total (i.e. unfiltered) 5-day biochemical oxygen demand
TKN	total Kjeldahl nitrogen
TN	total nitrogen
TOC	total organic carbon
TSS	total suspended solids
VFA	volatile fatty acids
WAS	waste activated sludge

1 Introduction

1.1 WHY THIS REVIEW?

The City of Winnipeg (City) provides treatment of wastewater generated by its community via the North End, West End and South End Wastewater Pollution Control Centres. It is a challenging service to provide because of the many complexities of this infrastructure and the demands of its operations. On this latter point, the City, like all such service providers, faces factors that are within and outside of its own control. Even for those it can control, the City may still encounter another dimension of cause-effect relationships that may not be obvious or well understood. Treatment process upsets are an example of such operations challenges and they set the context of this review.

In the latter part of 2011 the City of Winnipeg experienced a major upset with the biological (secondary) treatment process at the South End Wastewater Pollution Control Centre (SEWPCC). The main consequence was the discharge of effluent to the Red River, over an extended period, which did not comply with the requirements of the *Environment Act* License No. 2716 R that applies to this facility. To this end, Manitoba Conservation and Water Stewardship retained Associated Engineering to conduct a review with the following broad objective:

> *The objective of this project is to review the technical and supporting information supplied by Manitoba Conservation* and Water Stewardship *and to diagnose and evaluate the systems, processes and procedures in place with the South End Wastewater Pollution Control Center itself and the City of Winnipeg Water and Waste Department as it relates to the South End Plant, and to make recommendations of potential changes or corrective actions that would prevent a similar occurrence and/or mitigate the impact of a similar occurrence.*

1.2 DOCUMENT ORGANIZATION

The remainder of this document is organized into eight main sections. Section 2 documents the technical review of the event with a specific focus on its cause or trigger. Independent of this specific event, Sections 3, 4 and 5 summarize City procedures related to emergency response plans, environmental management systems, and internal communications protocols, respectively. Using information provided to Manitoba Conservation and Water Stewardship by the City, Section 6 then describes how the City responded to the event in terms of these non-technical procedures. Moving back to the realm of the technical, Section 7 explores how the City responded to the event with a focus on choices available, actions taken, and use of time. Set in the context of the probable event trigger identified in Section 2, and in light of the findings discussed in Sections 6 and 7, Section 8 offers observations and insights related to gaps in the SEWPCC operating procedures, the emergency response plan, infrastructure and communications. From these findings, Section 9 outlines key conclusions and recommendations for Manitoba Conservation and Water Stewardship to assist the City in responding to and mitigating impacts of subsequent, similar events.

1.3 QUALIFICATION OF REVIEW

This high-level review utilized existing information provided by Manitoba Conservation and Water Stewardship as obtained from the City of Winnipeg. The information captures the time frame from approximately early October 2011 to the end of December 2011. No new information was generated by this review. Rather, the activity involved the extraction, synthesis and presentation of information that already exists. Although a site visit was undertaken to familiarize our team with the SEWPCC, no City staff interviews were undertaken by Associated Engineering per the direction of Manitoba Conservation and Water Stewardship.

The short review schedule necessarily allowed examination of only select information that was deemed relevant for the assignment. All practical efforts were made to ensure no significant oversight of information examined. Similarly, the commentary provided in this report gives a broad overview of the subject material and, by nature of the review scope, was not intended to pursue technical points in-depth.

1.4 ACKNOWLEDGEMENTS

This report has been prepared by Associated Engineering, working under contract to Manitoba Conservation and Water Stewardship. The primary author was Dr. Dean Shiskowski, P.Eng., who was supported by a technical team including Jeff O'Driscoll, P.Eng., Jeff Chen, M.A.Sc., P.Eng., Colin McKinnon, P.Eng. and Mike Whalley, M.Eng., P.Eng. Bringing extensive utility operations backgrounds to the project were Dr. Caroline O'Reilly, Bill de Angelis, MBA, P.Eng., and Dr. Klas Ohman, P.Eng., who are all Associated Engineering staff who participated in an internal project workshop and are acknowledged for their valuable insights. Project review was carried out by Bert Munro, P.Eng., FCSCE, FEC.

Information referenced in this report was provided by Manitoba Conservation and Water Stewardship, whom we acknowledge and thank for their prompt response to our inquiries and overall project guidance. We also acknowledge City staff for their cooperation in providing a tour of the SEWPCC.

2 Secondary Process Upset Evaluation

2.1 SEWPCC OVERVIEW

Before examining information and data relevant to the fall 2011 upset event, it is worthwhile to first review the SEWPCC in terms of its main wastewater treatment technologies and systems. In general, the SEWPCC provides the following *levels* of wastewater treatment as defined by Tchobanoglous et al. (2003):

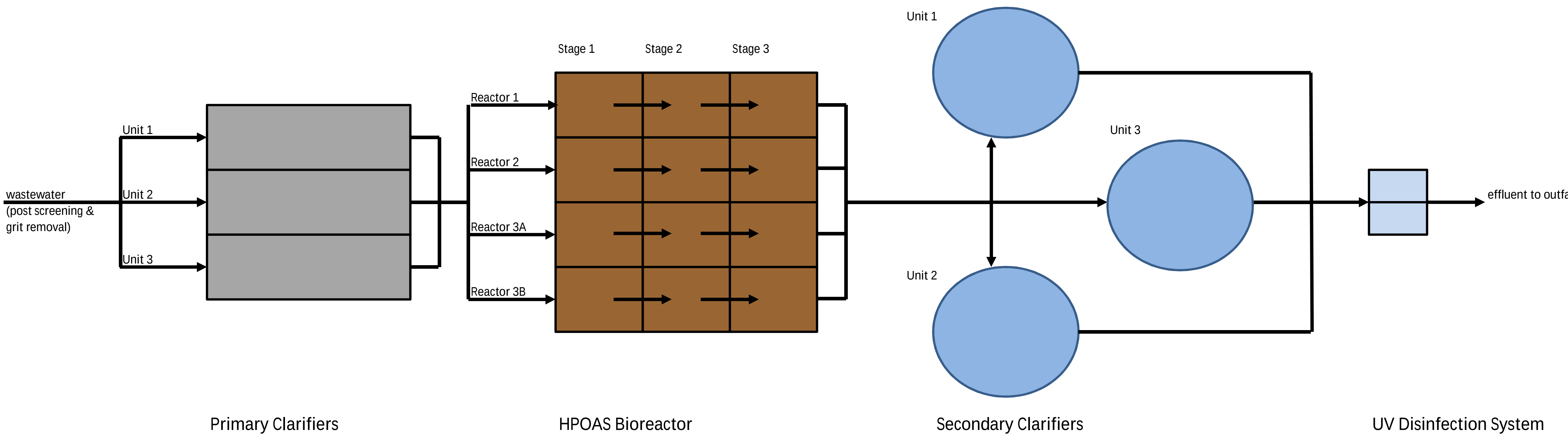
- **preliminary →** removal of wastewater debris, grease, floatable material and grit that can impact performance, operation and maintenance of downstream systems
- **primary →** removal of settleable and some colloidal fraction of suspended solids and organic material from wastewater
- **secondary →** removal of wastewater biodegradable organic matter and suspended solids, along with effluent disinfection to provide partial destruction of disease-causing organisms

Figure 2-1 illustrates, in plan view, a simplified process flow diagram (PFD) of the SEWPCC that shows the wastewater flow through the facility. Three (3) conventional primary clarifiers, operating in parallel and without any form of chemically-enhanced treatment, provide primary treatment of the incoming screened and de-gritted wastewater. The core secondary treatment system is what is known in the industry as a high-purity oxygen activated sludge (HPOAS) system (Grady et al. 1999), which consists of four (4) bioreactors operating in parallel, each containing 3 stages, followed by three (3) secondary clarifiers. In addition, an ultraviolet (UV) irradiation effluent disinfection system, which utilizes two parallel banks of UV lamps, is part of the secondary treatment system.

Figure 2-2 shows the SEWPCC's simplified PFD in section view, illustrating both the liquid-stream and solids-stream flows through the facility. Of particular note, primary sludge (PS) and waste activated sludge (WAS) produced by wastewater treatment are truck-hauled to the North End Wastewater Pollution Control Centre (NEWPCC) for biological stabilization and dewatering, which provides a biosolids product for an agricultural land application beneficial reuse program. Thus no on-site solids processing occurs at the SEWPCC.

The HPOAS bioreactors are intended to operate in a fully aerobic environment to provide wastewater carbon oxidation. Unlike a conventional activated sludge process, where atmospheric air is introduced into the bioreactors to provide oxygen to the biomass, an essentially pure oxygen (i.e. > 90% O_2) gas stream is fed into the headspace of the first stage in each bioreactor train (Figure 2-2). Rotating mixers keep the biomass in suspension within the reactors while simultaneously enhancing the gas diffusion of oxygen contained in the bioreactor headspace into the bulk liquid solution (mixed liquor). The gas stream flows concurrently with the mixed liquor through the various stages of the bioreactor and the headspace is vented to the atmosphere from the 3rd stage. Two skid-mounted pressure swing absorption (PSA) systems generate the pure oxygen feed gas from atmospheric air, which is fed by blowers to the bioreactors.

HPOAS	high-purity oxygen activated sludge
UV	ultraviolet



not to scale

Figure 2-1
SEWPCC simplified plan view process flow diagram showing liquid-stream flow only.

HPOAS	high-purity oxygen activated sludge
UV	ultraviolet
PSA	pressure swing absorption
O2	oxygen
PS	primary sludge
WAS	waste activated sludge
RAS	return activated sludge
NEWPCC	North End Wastewater Pollution Control Centre

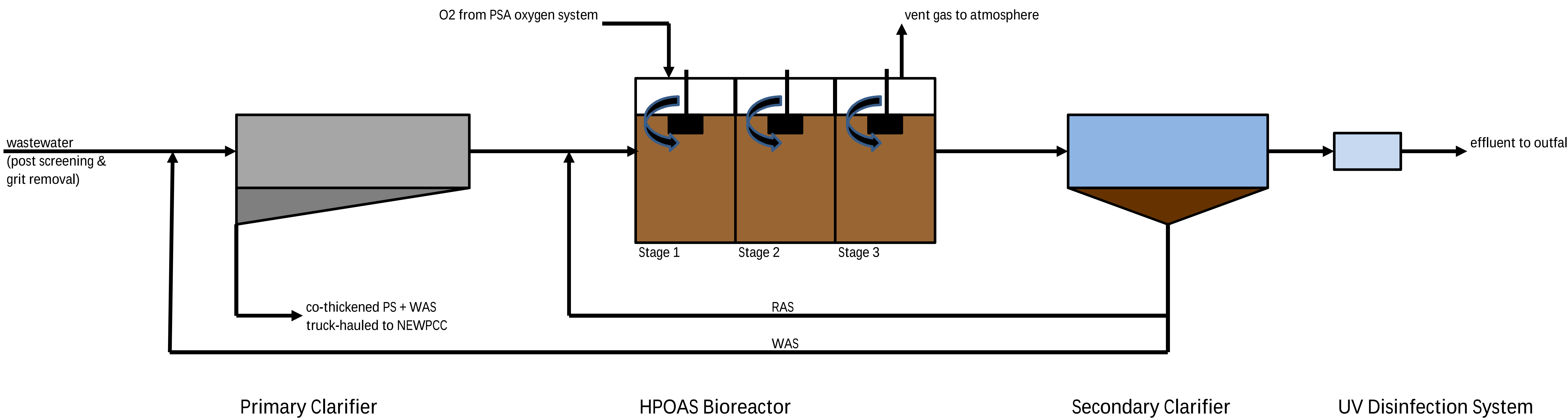


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Figure 2-2
SEWPCC simplified section view process flow diagram showing liquid-stream and solid-stream flow.

By design the high-rate HPOAS system operates at a very short (e.g. 2 d) solids retention time (SRT) that, in turn, maintains a biomass population with few nitrifying bacteria. Thus the system provides little conversion of reduced wastewater nitrogen compounds (i.e. organic nitrogen, ammonia) to oxidized species such as nitrate.

2.2 EVENT MANIFESTATION

The causes of biological system upsets can be broadly grouped into categories that include enzyme system inhibition / cellular function disruption, cell rupture / integrity loss, biomass de-flocculation and microbial population shifts. The system response to these events can manifest themselves in reduced oxidation of wastewater compounds and thus reduced bioreactor oxygen uptake rates and ultimately poor effluent quality, excessively turbid and high suspended solids levels in final effluent, and loss of secondary clarifier sludge blankets to the effluent due to excess filamentous organism growth as some respective examples. Ultimately, secondary and final effluent quality can be significantly compromised.

The SEWCC biological process “upset” manifested itself in a rapid rise in final effluent total suspended solids (TSS) levels around October 6, 2011 (Figure 2-3).

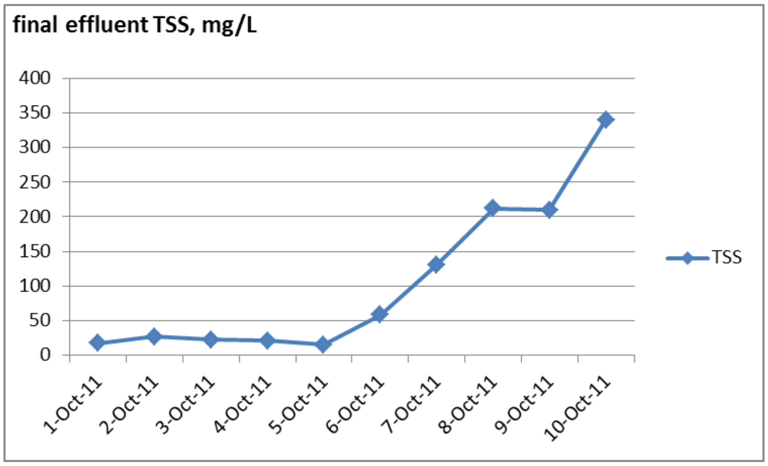


Figure 2-3
Final Effluent TSS Concentration

Concurrent with the high effluent TSS levels was the rising thickness of the measured secondary clarifier sludge blankets in each of the three units (Figure 2-4). The degradation of the mixed liquor compaction / thickening properties was also evident in the rapidly increasing mixed liquor sludge volume index (SVI) values (Figure 2-5). Data were not available for days shown without any values.

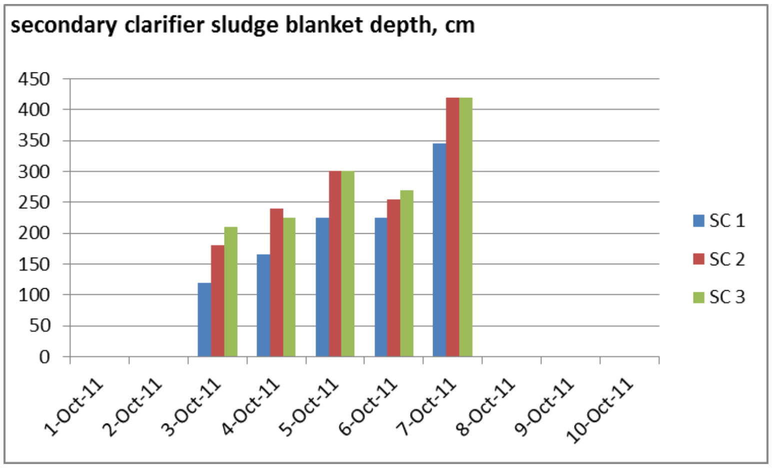


Figure 2-4
Secondary Clarifier Sludge Blanket Depth

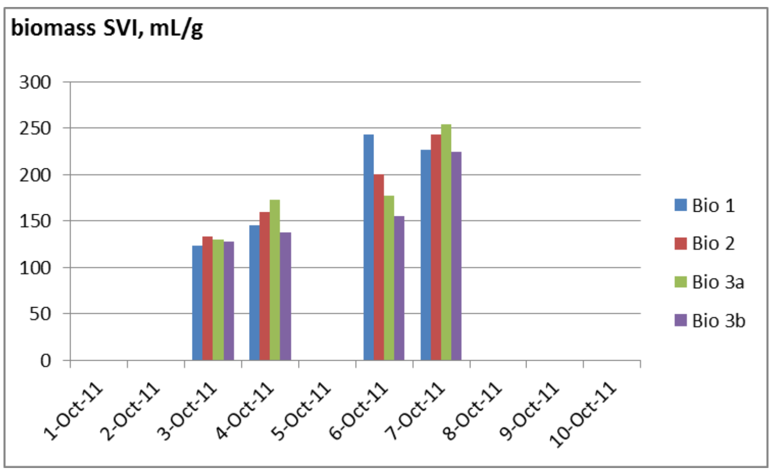


Figure 2-5
Biomass Sludge Volume Index

All of these observations are indicative of *filamentous bulking*, where the biomass in the bioreactor shifts from having a microbial population with a balanced mixture of floc-forming organisms and filamentous organisms, which provides a rapid settling biomass with good thickening properties, to one dominated by filamentous organisms that produces the opposite situation. Ultimately, as this occurs, secondary clarifier effluent quality is compromised as the hydrodynamic forces within the tankage carry water with increased TSS levels, originating from the rising sludge blanket, into the clarifier outlet.

Biomass samples, obtained from the waste activated sludge (WAS) line and first collected on October 21, 2011 and subjected to City of Winnipeg Analytical Services Branch microscopic analysis, were found to be “dominated” by the filamentous organism *Sphaerotilus natans* (*S. natans*). Independent analysis of samples collected on November 2, 2011 by the City (Richard (2011)) reached a similar conclusion – a high amount of filaments with *S. natans* being most significant.

In the end, the SEWPCC final effluent quality was compromised for an extended duration. Figure 2-6 shows final effluent TSS and total 5-day biochemical oxygen demand (TBOD) concentrations for 24-hr composite samples. From early October through much of November 2011 parameter concentrations were in excess of the 30 mg/L limit stipulated in Manitoba Conservation and Water Stewardship License No. 2716 R, which is also shown in the figure. A similar situation existed for both fecal coliform and E. coli, where the License requires the geometric mean of three samples collected on consecutive days, once a month, to meet a 200 MPN/100 mL limit (Figure 2-7a/b, Figure 2-7b uses a reduced vertical scale).

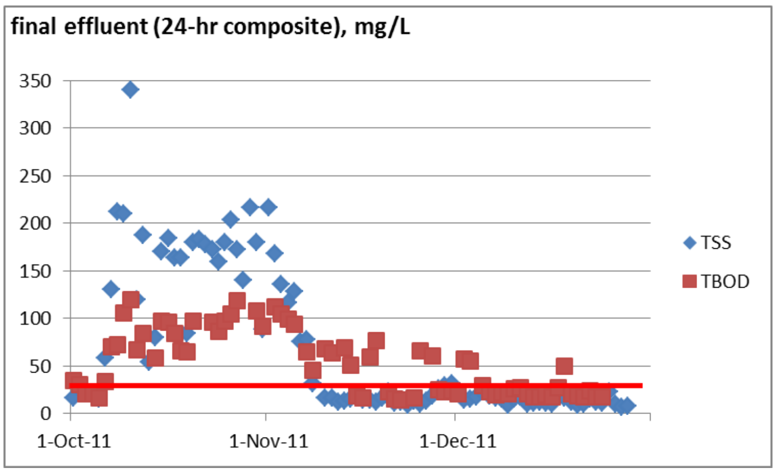


Figure 2-6
Final Effluent TSS and TBOD Concentration

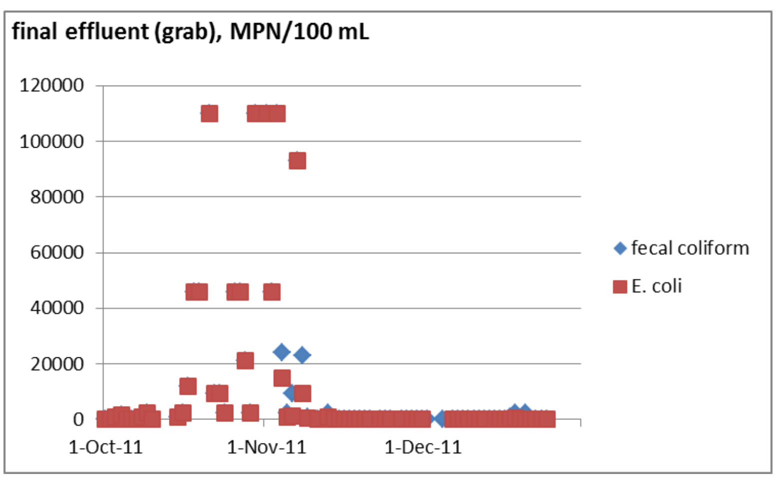


Figure 2-7a
Final Effluent Fecal Coliform and *E. coli* Concentration

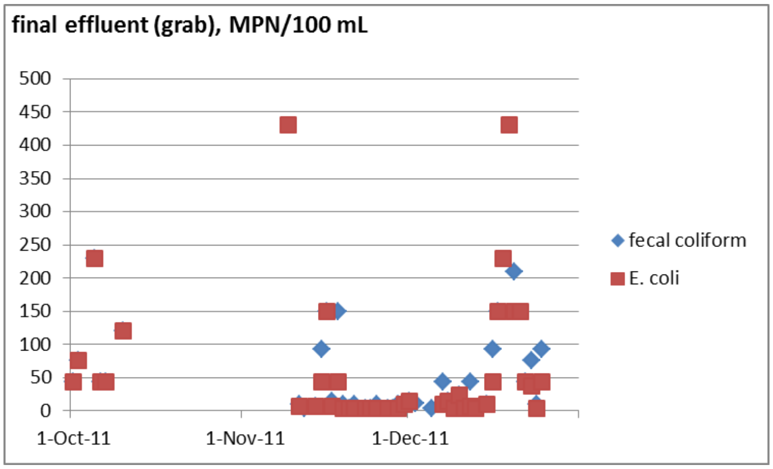


Figure 2-7b
Final Effluent Fecal Coliform and *E. coli* Concentration (reduced scale)

Finally, one last observation regarding the manifestation of this event is noteworthy. The rapid rise in final effluent TSS levels in early October was expectedly accompanied by a comparable rise in TBOD (Figure 2-8) concentrations, since the TBOD is influenced by the oxygen demand associated with oxidation of the particulate matter along with truly soluble material. Similarly, effluent total nitrogen (TN) levels rose alongside TSS since the particulate nitrogen fraction of effluent TSS contributes to the TN concentration. The rise in observed effluent TN concentration during the period shown (i.e. 19 mg N/L) correlates reasonably well with that estimated (i.e. 28 mg N/L) due to the increase in TSS concentration (i.e. when accounting for the nitrogen content of the suspended solids, assuming the biological cells in the effluent have a composition of $C_5H_7NO_2$ and the volatile fraction of the TSS, which can reasonably be assumed to represent the cellular fraction of the effluent TSS, is 85% of the TSS concentration), once adjusted for differences in ammonia concentration. The observed 19 mg N/L increase also compares reasonably closely with the observed 24 mg N/L change in effluent organic nitrogen concentration, calculated using measured effluent ammonia and total Kjeldahl nitrogen (TKN) values. This information suggests that the amount of ammonia used by the biomass for cell synthesis and growth remained relatively constant during this period, which, in turn, implies the biomass as-a-whole did not experience notable enzyme system inhibition / cellular function disruption or cell rupture / integrity loss.

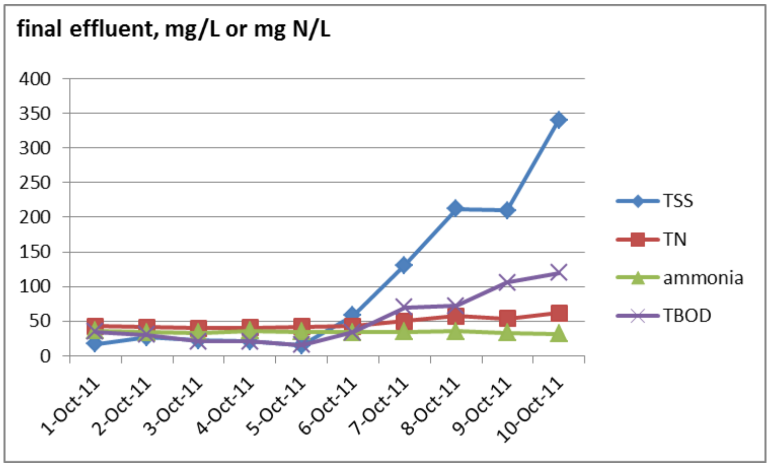


Figure 2-8
Final Effluent TSS, Total Nitrogen, Ammonia and TBOD Concentration

2.3 INITIAL SCREENING OF POTENTIAL EVENT TRIGGERS

As discussed in Section 2.2, the information available suggests that the process “upset” of early October 2011 was a filamentous bulking event that resulted in elevated secondary and final effluent TSS, TBOD, fecal coliform and *E. coli* levels. Microscopic analysis of biomass samples, first collected several weeks after the event was triggered, discovered the presence of high levels of the filamentous organism *S. natans*. This finding corroborates the filamentous bulking theory.

The question is now – what triggered the bulking event, and more specifically, the proliferation of *S. natans* relative to the floc-forming organisms typically present in biomass?

Grady et al. (1999) present several causative conditions associated with observed, and excessive, presence of *S. natans*:

1) Low bioreactor dissolved oxygen (DO) levels
2) Bioreactors using a completely-mixed configuration that do not provide significant substrate concentration gradients across the stages
3) Nutrient deficiency

Condition 1) is related to bioreactor design and/or operation. Condition 2) is also associated with bioreactor design, but the extent to which it may be important can be related to wastewater composition. Condition 3) is a wastewater characteristic that, if known, can be addressed through system design (i.e. typically in known nutrient-deficient industrial wastewaters where nutrients are purposely added to the bioreactor). Seviour and Nielsen (2010) add a fourth condition for consideration:

4) Inoculation from sewer system

They note that filamentous organisms like *S. natans* can be found in biofilms within sewer systems. These biofilms slough off the pipes and other infrastructure elements of the collection system and thus "inoculate" the bioreactors at treatment facilities with organisms contained in the sloughed material.

No specific data or information was provided for this review that suggests **Condition 4)**, bioreactor inoculation of *S. natans* from the sewer system, was a probable, single trigger of the bulking event. The average daily wastewater flow rate received at the SEWPCC during the first week of October 2011 was very constant and ranged between 49.0 and 51.1 ML/d. Thus, in the absence of a significantly high flow (i.e. wet-weather) event to scour the collection system and remove biofilm from material surfaces, it seems unlikely Condition 4 was a significant factor in triggering the bulking event.

In relation to **Condition 3)**, nutrient deficiency, raw wastewater and final effluent concentrations of the *macro nutrients* nitrogen and phosphorous were typical and do not indicate an obvious limitation. However, work by Manoharan et al. (1992) found bio-available phosphorus limitations can exist in the presence of suitably high total phosphorus concentrations because of the formation of metal-phosphate precipitates (i.e. zinc phosphate). Their research discovered that bio-available phosphorus was best estimated in samples first filtered using 0.45 µm membrane filters rather than larger pore size glass fibre filters. Review of raw wastewater "dissolved" P concentrations in 24-hr composite samples collected during the first week of October show consistent, and typical, levels (i.e. 4.1 to 6.0 mg P/L). However, at this time we do not know the exact laboratory procedures used by the City in terms of the dissolved P data available and we cannot comment further on bio-available P. Regardless, it is possible that the discharge of a significant amount of metal-bearing wastewater to the collection system could potentially create a situation that could cause a nutrient limitation at the SEWPCC. However, metal-phosphate precipitates are an unlikely explanation given the shear mass of metals that would need to be discharged to the collection system to impact the total wastewater flow to the extent required.

Micro nutrients, or trace elements, such as potassium, magnesium and iron are also essential for the organisms used in biological wastewater treatment and work done by Wood and Tchobanoglous (1975) demonstrated micro nutrient importance and potential role in bulking events. No specific information was available for our review in the context of micro nutrient limitations. This trigger cannot be ruled out but, again, would seem unlikely in this specific situation.

Assessing the potential of **Condition 2)**, bioreactor mixing / substrate gradient, requires knowledge of the readily biodegradable substrates (e.g. alcohols, volatile fatty acids, etc.) in the wastewater along with their concentrations in the mixed liquor of each of the 3 stages of the bioreactors. Again, no such specific information was available for this review. The City does analyze wastewater for what we interpret to be soluble organic carbon (i.e. filtered wastewater subjected to total organic carbon analysis). There is some question as to the ability of 24 hour composite samples and the analysis methodology to capture wastewater readily biodegradable substrates that may be volatile in nature (e.g. volatile fatty acids). That said, nothing in the early October wastewater soluble organic carbon data looks notably atypical relative to other data for October and November. Volatile fatty acids (VFAs) can be produced by fermentation of PS and WAS thickened in the primary clarifiers, subsequently ending up in the primary effluent that flows into the bioreactors. Thus it is possible that the primary effluent fed to the bioreactors did contain an elevated fraction of readily biodegradable substrates that, in turn, could implicate Condition 2) as part of the trigger of the bulking event.

Based on a process of elimination, **Condition 1)**, low bioreactor DO levels, may offer the most plausible, primary explanation for the bulking event trigger. Section 2.4 further examines this proposition.

2.4 HYPOTHESIZED EVENT TRIGGER AND CAUSE

Figure 2-9 provides a potential clue as to what may have triggered the event. Here it can be seen that the primary effluent (PE) TSS concentration (290 mg/) recorded for the October 6 sample was substantially higher than the preceding days when the TSS level was consistently around 100 mg/L. Although not shown in Figure 2-9, PE TSS levels for most October and November samples were normally in the 80 to 120 mg/L range, which suggests that the October 6 value of 290 mg/L was very atypical under the dry-flow wastewater flow conditions experienced in early October. As mentioned earlier, data were not available for days shown without any values.

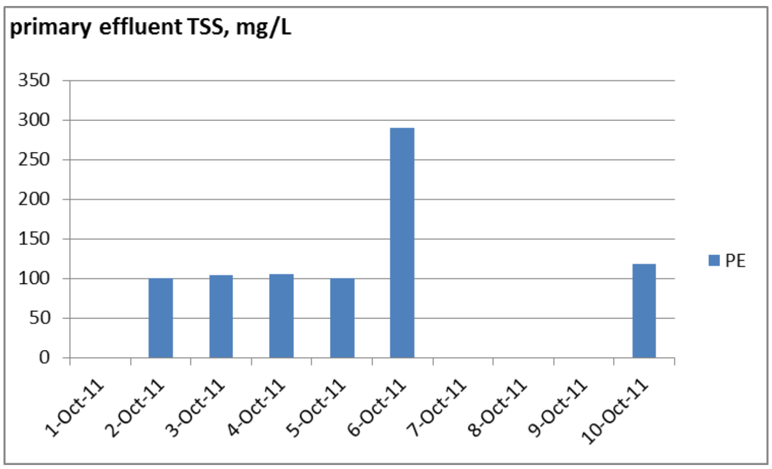


Figure 2-9
Primary Effluent TSS Concentration

Simultaneous with the extreme increase in PE TSS concentration was a large increase in bioreactor mixed liquor suspended solids (MLSS) concentration as measured on October 6 (Figure 2-10). Based on other sample collection protocols, we believe that the MLSS values represent a "single point" measurement taken on the day recorded for the sample. Alternately, the 24-hr composite PE samples may represent the 24-hr period *prior* to sample collection and the recorded date. If this interpretation is correct, the high PE TSS value recorded for October 6 may have included a sampling period that extended into October 5. Therefore, this situation may explain the increase in bioreactor MLSS levels from October 4 (i.e. no data available for October 5) to October 6 given the high PE TSS loading suggested by the TSS sample dated October 6.

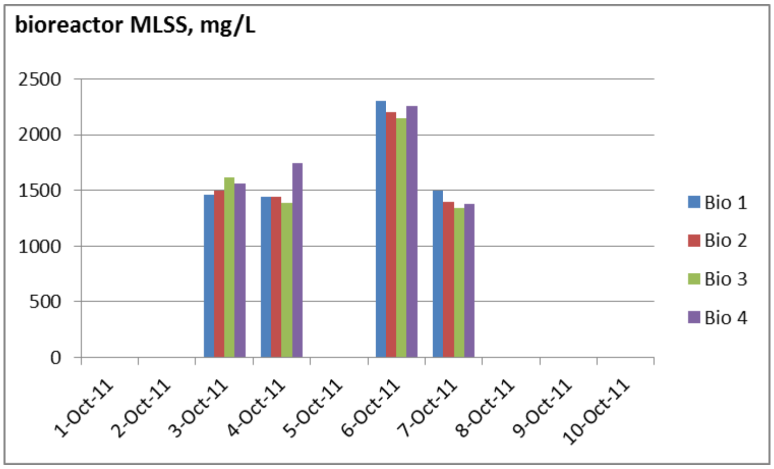


Figure 2-10
Bioreactor MLSS Concentration

Why are these observations relevant? Given everything else being constant, a rapid and significant increase in the mass of solids contained in the bioreactors will increase the biomass demand for oxygen (i.e. oxygen uptake rate, OUR). If the bioreactor oxygen mass feed rate does not change in response to the increased OUR, the mixed liquor DO levels will drop, potentially to levels that could cause S. natans to have a competitive advantage over the floc-forming organisms and thus proliferate relative to other organisms.

Is this hypothesis consistent with other data? Figure 2-11 shows the bioreactor oxygen consumption for the same October period and indicates minimal change in all the bioreactors, with the exception of unit 3a, across the October 3 to 7 dates. What is notable, however, are the lower oxygen consumption values for October 2. We understand that SEWPCC staff noted a reduction in bioreactor MLSS levels and reduced the WAS flow, to increase biomass SRT, on October 3. Reduced MLSS levels could explain the lower oxygen consumption, but no MLSS data were available for the first few days of October to corroborate this suggestion.

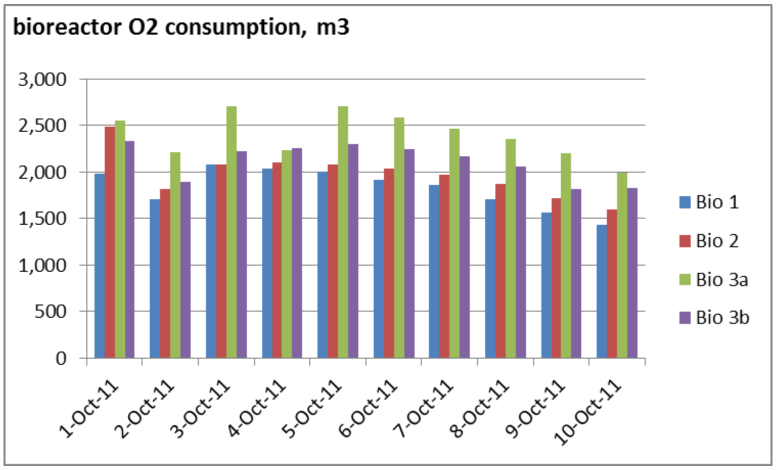


Figure 2-11
Bioreactor Oxygen Consumption

Alternately, for these same dates the vent gas oxygen purity concentrations showed a significant change for bioreactors 2 and 3A (Figure 2-12). Coincidentally, the mixed liquor DO levels displayed a similar pattern for these dates (Figure 2-13).

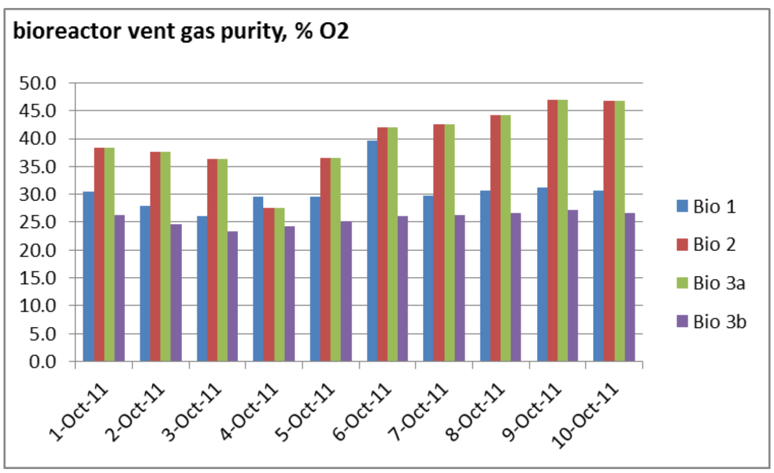


Figure 2-12
Bioreactor Vent Gas Purity

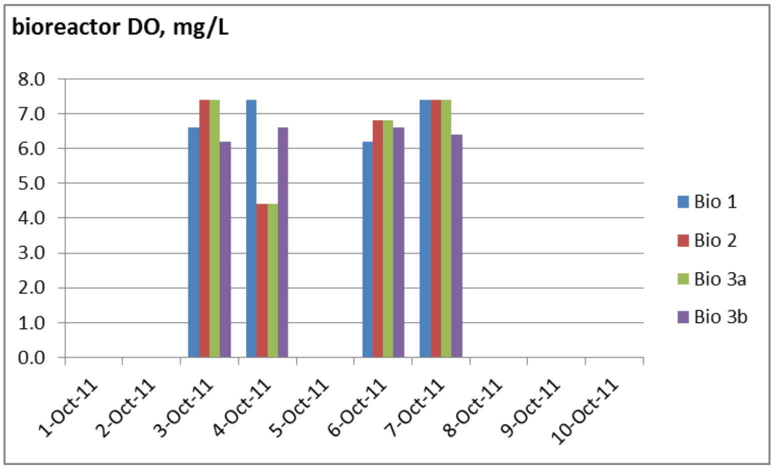


Figure 2-13
Bioreactor Mixed Liquor DO Concentration

The large increase in bioreactor MLSS levels on October 6 (Figure 2-10), presumably due to the high PE TSS loading on October 5 to 6 (Figure 2-9), should have manifested itself in substantially higher bioreactor oxygen consumption rates but did not according to the Figure 2-11 values. Assuming the oxygen supply rate remained constant during this period, which the Figure 2-14 data suggest to be the case, a “dip” in bioreactor vent gas purity (Figure 2-12) and bioreactor DO concentrations (Figure 2-13) would be expected due to the higher biomass OUR if the oxygen supply system could not keep up with demand. Such a dip did occur, but seems to have occurred slightly earlier than October 5 to 6.

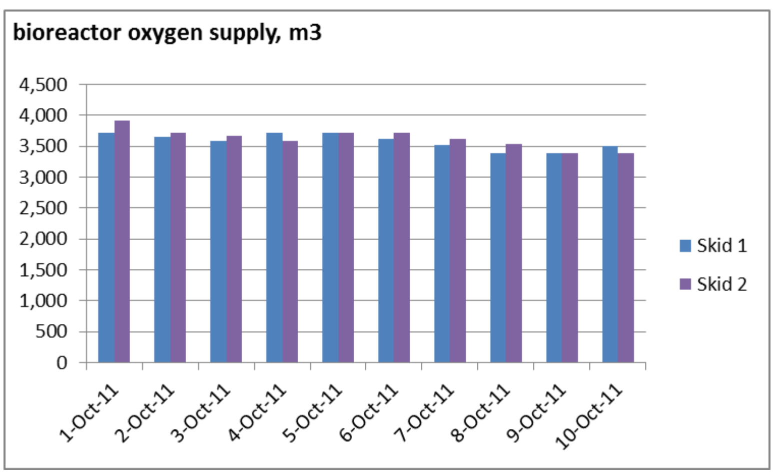


Figure 2-14
Bioreactor Oxygen Supply Rate

Related to Figure 2-14, the SEWPCC “work history report” indicated that PSA Skid 2 shut down on October 2 and a liquid oxygen (LOX) system was then initiated. However, based on the Figure 2-14 values, it appears this situation did not affect bioreactor oxygen supply.

The SEWPCC work history report also noted an issue with the bioreactor #2 oxygen vent valve control on October 5. This issue might explain the notably lower bioreactor #2 vent gas purity value for October 4 shown in Figure 2-12. It may also explain the depressed DO concentration shown in Figure 2-13 for October 4, but this cannot be ascertained with certainty from the information made available for review.

Part of the inconsistency in these data may again be explained by the data themselves. We understand that the bioreactor DO values originate from single-point measurements taken in the early afternoon. These limited measurements may not capture periods of the day when lower DO levels might exist because of diurnal loading variations. In addition, the measurements were taken in the mixed liquor junction chamber located immediately behind the 3rd stage of each bioreactor. This latter point is particularly important as the DO depletion induced by a high PE TSS loading event would be most significant in the first stage of the bioreactor, at least initially, until the load shifted to latter stages. Thus the DO data available in early October provide only limited insight into the event.

To gain some further perspective into the event we created a computer model of the SEWPCC using the BioWin™ software package and calibrated (i.e. a high-level calibration) the model using facility data from early October 2011, known tankage volumes and various SEWPCC operating conditions. Figure 2-15 shows the model configuration, which included a “simulated PE” element that allowed the return of some of the primary sludge to the primary effluent. Once activated in a dynamic simulation, this element allowed the simulation to replicate the high PE TSS concentration of approximately 300 mg/L (i.e. Figure 2-6).

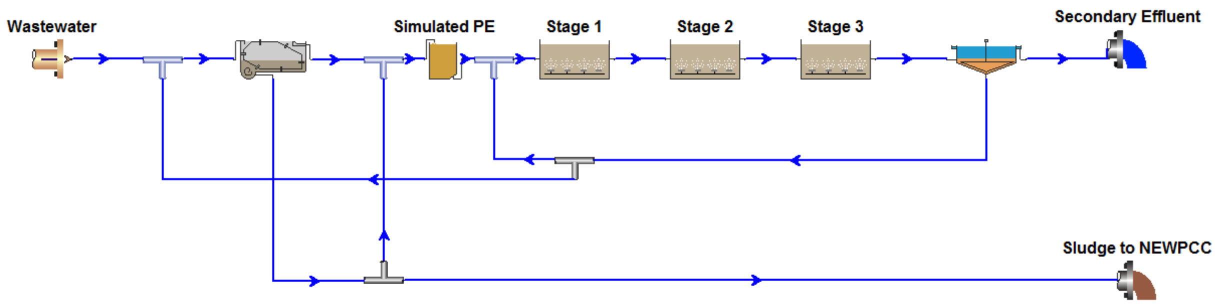


Figure 2-15
BioWin™ Model Configuration of SEWPCC

Figure 2-16a shows the simulation results, beginning with the predicted PE TSS levels. Day 1 of the simulation was conducted at steady-state and provided a PE TSS concentration of approximately 100 mg/L (i.e. typical concentration). On day 2, some of the primary sludge was directed to the primary effluent to simulate partial loss of the primary sludge blanket, which was done to provide a PE TSS concentration of about 300 mg/L (i.e. observed during the October event).

Figure 2-16b illustrates the predicted effect on the bioreactor MLSS levels, which increased by approximately 55%. This relative increase reasonably matches the observed increase shown in Figure 2-10 between October 4 and 6.

Figure 2-16c shows the resulting effect on the bioreactor OUR in each of the three stages. By the end of simulation day 2 the predicted OUR increased by about 25% in the 1st stage of the bioreactor and approximately 50% in the 2nd and 3rd bioreactor stages.

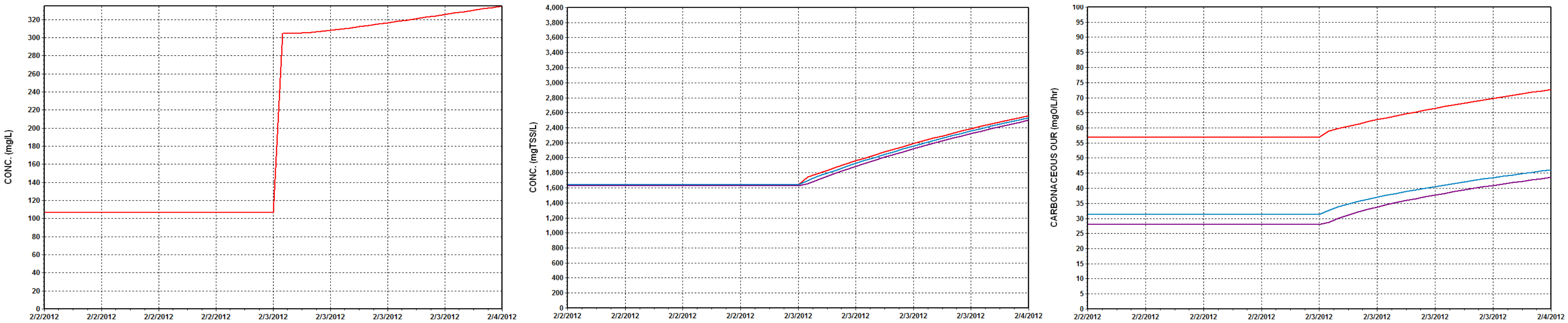
The simulations findings should not be taken as absolute. But they do indicate the potentially significant effect on bioreactor OUR that primary sludge blanket loss, which manifests itself in high PE TSS levels, can induce occur over a short period of time. If the oxygen supply system cannot respond to the OUR increase, in-situ DO levels will fall and potentially to levels that might trigger *S. natans* proliferation. The actual DO concentration that could trigger this situation is dependent on the organic carbon process loading factor (PLF) (Grady et al., 1999; Seviour and Nielsen, 2010), which influences the inter-floc oxygen diffusion dynamics. Therefore, both DO level and PLF are intimately linked in such filamentous bulking events and DO concentrations that are considered relatively high may not prevent growth of “low DO” filamentous organisms.

As discussed in Section 7.3, the City began to manipulate the bioreactor oxygen supply / vent gas purity (starting late-October) and simultaneously measure mixed liquor DO levels in all bioreactor stages (starting mid-November). These data show that DO levels in excess of 15 mg/L could typically be achieved in the 1st stage of all bioreactor trains, with the 3rd stage DO levels almost always in excess of 20 mg/L; all these values are substantially higher than those shown in Figure 2-13. The difference in values could be an artifact of the sampling location, i.e. the biomass might have consumed some of the DO in the early October samples by the time the measurements were taken after the mixed liquor exited the 3rd bioreactor stage. Alternately, the oxygen system manipulations may have contributed to a real increase in mixed liquor DO levels.

There is one other potential factor around the oxygen supply and DO / PLF topic. Both the internal and external laboratories that analyzed RAS samples found notably high numbers of *Nocardia* spp., which is a genus of organisms associated with foaming and foaming events. Seviour and Nielsen (2010) state that one of the potential problems associated with foaming is the reduction of oxygen transfer efficiency across the surface of mechanically aerated bioreactors. Therefore, while sufficient oxygen may have been supplied to the bioreactors in the 1st stage headspace, the presence of foam on the liquid surface may have reduced the transfer of oxygen across this surface and into the bioreactor mixed liquor. This situation could potentially result in mixed liquor DO levels being lower than would normally be expected for a given oxygen supply rate.

The information presented to this point does lend evidence to the low DO trigger for *S. natans* growth, which could be related to the high PE TSS mass loading to the bioreactors on October 5 to 6. The question remains, however, as to what caused this high loading situation.

First, consider the raw wastewater TSS and TBOD levels in early October shown in Figure 2-17. While there was a large increase in sample TBOD concentration between October 6 and 8, TSS levels show a slightly declining trend and with a large decrease on October 7.



a) Predicted Primary Effluent TSS Concentration, mg/L

b) Predicted Bioreactor MLSS Concentration, mg/L

c) Predicted Bioreactor OUR, mg O2/L-hr

Figure 2-16
Simulation-Predicted Values

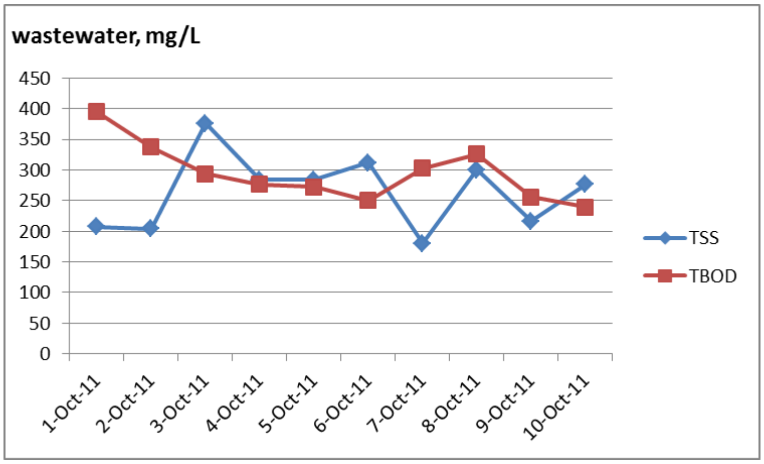


Figure 2-17
Wastewater TSS and TBOD Concentration

Based on the TSS data trend, and recognizing that the wastewater flow entering the SEWPCC was essentially constant on a 24-hr volume basis in early October, it does not appear that a loss of primary clarifier TSS removal efficiency was the cause of the high PE TSS concentration recorded for October 6.

Trucked waste (e.g. septage) received at the SEWPCC is another potential source of high solids loading to the facility. However, the estimated 4,600 kg increase in bioreactor solids between October 4 and 6 would require the receipt of over 20 trucks (e.g. 22.7 m^3 / truck with a TSS concentration of 10,000 mg/l) of material and the unlikely assumption that none of the solids would be removed in the primary clarifiers. No City data were available for trucked waste load characterization for early October.

As alluded to previously, another potential cause of the high PE TSS concentration in the October 6 sample is the partial “loss” of the primary sludge blanket to the primary effluent. Figure 2-18 shows the available primary sludge blanket depth data for the first ten days of October. The values are very erratic, likely due to the fact that they represent single-point measurements taken daily at about 8:30 a.m. On their own these data do not suggest primary sludge blanket loss that coincides with the high October 6 sample PE TSS value. Conversely, the data cannot rule it out either.

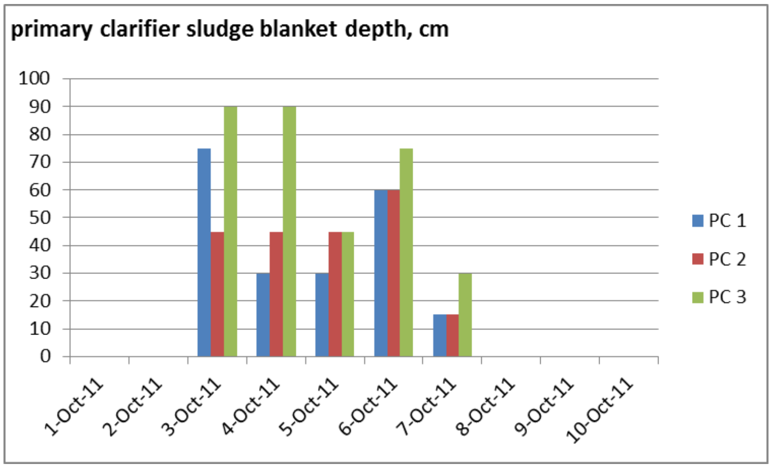


Figure 2-18
Primary Clarifier Sludge Blanket Depth

Regardless of the blanket depth data, there was no obvious cause for primary sludge blanket loss during this time period:

- The wastewater flow entering the SEWPCC was fairly constant during this time frame on a totalized 24-hr basis, suggesting there was not a hydraulic surge that might have re-suspended primary sludge and carried it into the primary effluent
- None of the SEWPCC daily maintenance / operations logs indicate a temporary flow stoppage to the SEWPCC (i.e. done occasionally by shutting down the wastewater pumps, and allowing wastewater to back up into the interceptor for up to approximately 4 hr, for facility maintenance purposes) that could have resulted in a short-duration hydraulic surge through the plant upon pump start-up that, in turn, may have scoured and re-suspended settled primary sludge
- All process equipment and tanks were on-line during this period, which would eliminate the possibility for high unit flow rates to re-suspended primary sludge.

Atypically high PE TBOD concentrations, and resultant bioreactor loadings, could also increase the biomass OUR and result in a depressed DO condition. Indeed, Figure 2-17 shows that the *wastewater* TBOD concentrations were very high in early October. However, PE TBOD data were not available and the consistent PE total organic carbon (TOC) values, shown in Figure 2-19, provide no suggestion of increased wastewater PE TBOD concentrations or loading over this period.

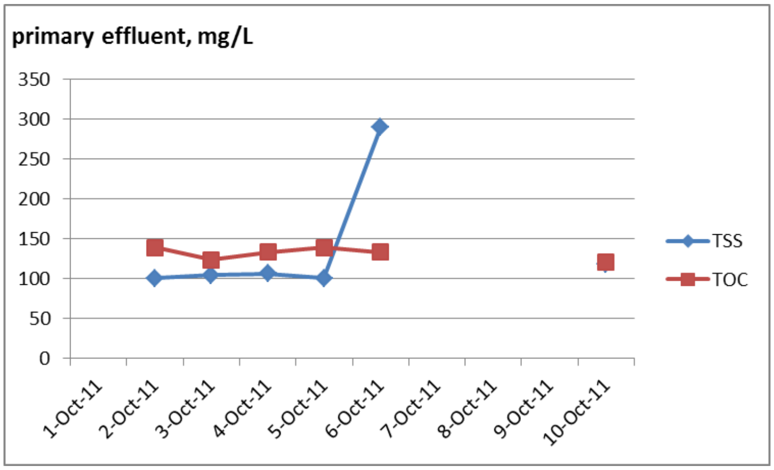


Figure 2-19
Primary Effluent TSS and TOC Concentration

The discussion must now come back to the October 6 recorded PE TSS value of 290 mg/L. The City confirmed the 290 mg/L value on request of Manitoba Conservation and Water Stewardship. However, there is still some question of its validity since PE TOC levels were consistently around 130 mg/L during the first six days of October. We would have expected that the PE TOC concentration for the October 6 sample would be notably elevated, relative to the other days, because of the additional suspended solids contained in the sample. A sampling or sample preparation error could explain the low TOC value. Similarly, an error could explain the high TSS concentration.

Alternatively, assuming the PE 290 mg/L TSS value is erroneous, what could cause such a rapid rise in bioreactor MLSS levels between October 4 and 6? Information provided by Manitoba Conservation and Water Stewardship and Water Stewardship indicates that SEWPCC staff noticed reduced bioreactor MLSS levels on October 3 and immediately reduced the WAS flow rate to increase biomass SRT and restore the MLSS concentration. No information was provided as to the extent of this manipulation. However, additional BioWin^{TM} simulations (data not shown) conducted do indicate that, depending on the extent of WAS flow rate manipulation and effluent TSS concentrations, it is possible to create a situation that may result in the rapid rise of bioreactor MLSS levels depicted in Figure 2-10.

In summary, of the four potential event triggers presented in Section 2.3, Condition 1, low bioreactor DO levels, does appear to be the most likely event trigger. However, gaps in available information make it difficult to fully understand the events of early October 2011 that led to triggering of the filamentous bulking event and, as a result, the exact cause of this trigger is uncertain. That said, it would be reasonable to suggest that its cause may be a combination of factors.

2.5 A "TOXIC" EVENT?

City statements in some of the reviewed information suggested that the October upset event may have been a "toxic" event due to discharge of some type of contaminant(s) to the wastewater upstream of the SEWPCC.

The first difficulty with these statements is one of available information; the City, it appears, did not immediately collect any samples for any type of analysis that could be used to support this idea from solely a wastewater characterization perspective. Later, the City did collect wastewater and final effluent grab samples for the analysis of a wide suite of wastewater constituents, including metals and organic compounds, on November 1, 2011. By this time any contaminants discharged to the sewer system in early October would have passed through the treatment facility, including those bound to biomass contained within the SEWPCC. We understand that a sample of floating, dark-coloured sludge was collected from a secondary clarifier in late October (27) and submitted for hydrocarbon analysis.

Second, none of the regularly collected operations data suggest that the biomass as-a-whole experienced notable disruption of enzyme or other cellular functions that can manifest itself in reduced biomass oxygen uptake rates and increasing bioreactor DO levels under continued and comparable oxygen supply rates.

Third, for the major groups of micro-organisms typically present in the SEWPC bioreactors to support the transformations intended (i.e. carbon oxidation only, with no nitrogen oxidation), none of the scientific literature we reviewed for this study associate filamentous bulking events with the kind of "toxic" event suggested in some City statements. The Water Environment Research Foundation (WERF) has invested significant effort in "early warning system" research to address the issue of common process upsets induced by toxins. Effects of specific interest included biomass deflocculation, inhibition of catabolic and metabolic pathways (e.g. ineffective BOD removal, ineffective nitrification and denitrification), and poor biomass dewaterability / compression / settleablility (e.g. *non*-filamentous bulking and foaming) (Love et al., 2005; Love and Bott, 2000). None of this work specifically addressed filamentous bulking, which was considered a "facility operation condition" rather than a biological treatment upset caused by wastewater "disturbances" (Love and Bott, 2000) due to classes of chemicals represented by such constituents as cadmium, cyanide, octanol, 1-chloro-2,4-dinotrobenzene, and 2-4-Dinitrophenol (Love et al., 2005).

Based on these reasons, we believe it is unlikely, although possible, that the October upset event was the result of a toxicant(s) discharged to the collection system.

3 SEWPCC Emergency Response Plan - General Review and Summary

3.1 OVERVIEW

As highlighted in Section 1.2, the report shifts now to “non-technical” corporate system topics that may have relevance to the upset event, beginning with the emergency response plan in Section 3.

Independent of the October 2011 SEWPCC event itself, Section 3.2 summarizes City emergency response protocols using flow chart graphics to convey the information in an easy-to-comprehend format. Section 3.2 presents the City “contingency plan” procedure CP-01S that is specific to the SEWPCC for “uncontrolled release of untreated / partially treated wastewater or sludge” as taken from the *City of Winnipeg Water and Waste Department Consolidated Emergency Response Plan* (CERP). Beyond this focused procedure, Section 3.2 also presents related emergency call-out and communications protocols that are described elsewhere in the CERP.

Section 6 addresses how the City ultimately adhered to these procedures and protocols in response to the October 2011 event based on the information available for this review.

3.2 FLOW CHART SUMMARY

Figure 3-1 is an adaptation of the flow chart contained in CP-01S, where we have added some limited, additional information from EP-10 (Emergency Call-out & Communications) and Appendix C (Reporting an Environmental Accident / Spill) of the CERP.

The technical actions triggered (i.e. repairs) are predicated on the cause of the release being a “physical or mechanical breakdown” as noted in the CP-01S procedure document and figure. In this case CP-01S initiates repair work as well as discharge (e.g. effluent) and receiving environment monitoring. From Figure 3-1 it can be seen that CP-01S does not provide technical guidance on how to respond to an uncontrolled release event of any specific type.

As illustrated in Figure 3-1, CP-01S does contain communications elements. However, to more holistically capture this aspect of the required event response, Figure 3-2 incorporates CP-01S material with other CERP sections and appendices that include Appendix B (Table of Regulatory Reporting Requirements), Appendix C (Reporting an Environmental Accident / Spill) and EP-10 (Emergency Call-out & Communications). We created this flow chart based on our interpretation of the reviewed *written* material as no graphical information was available. Thus while there is potential for some inaccuracy in our portrayal of the procedures we believe Figure 3-2 reasonably reflects the documents reviewed.

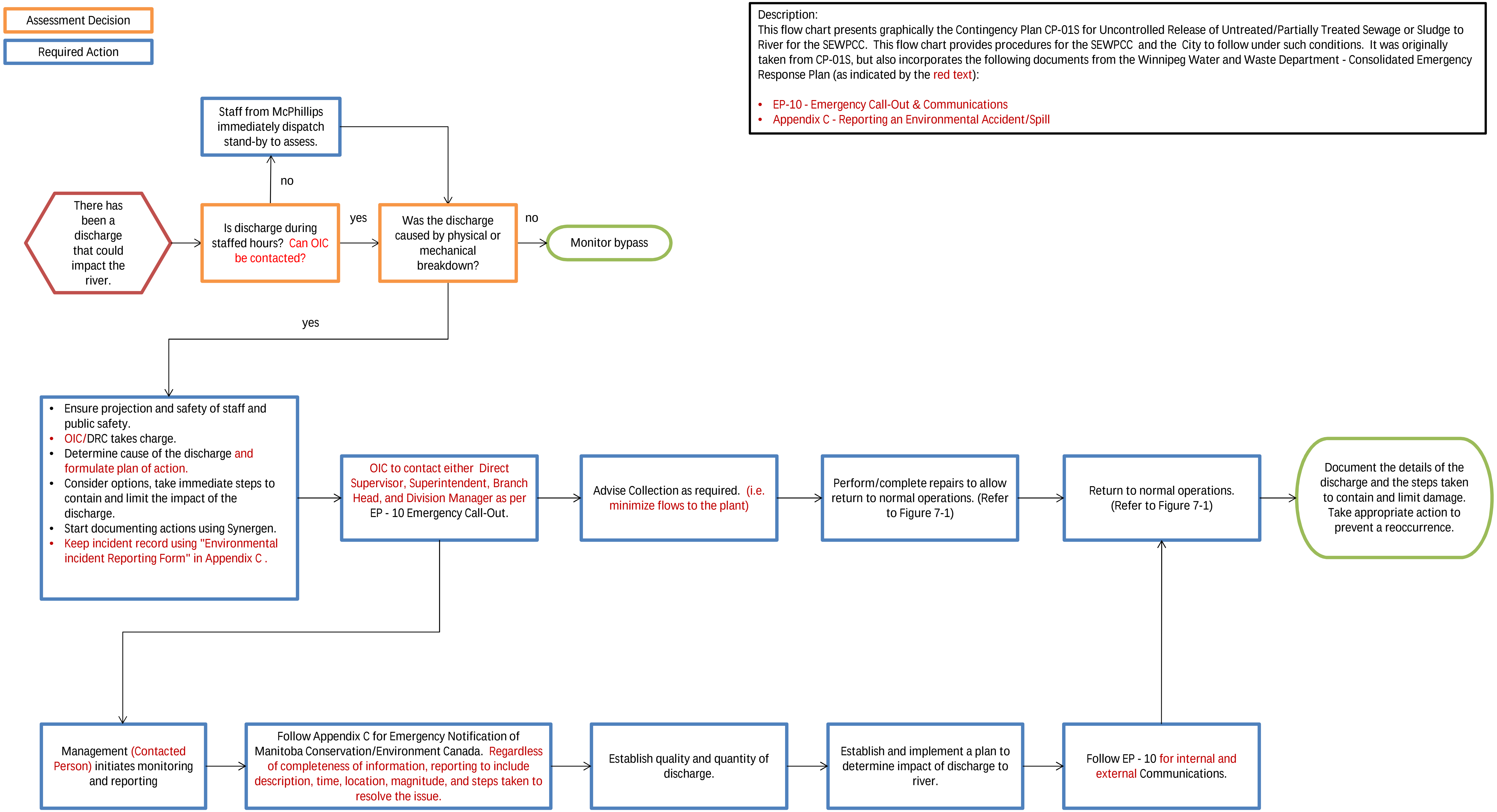


Figure 3-1
Flow Chart Summary of SEWPCC Emergency Response Plan for Uncontrolled Release of Untreated / Partially Treated Wastewater or Sludge

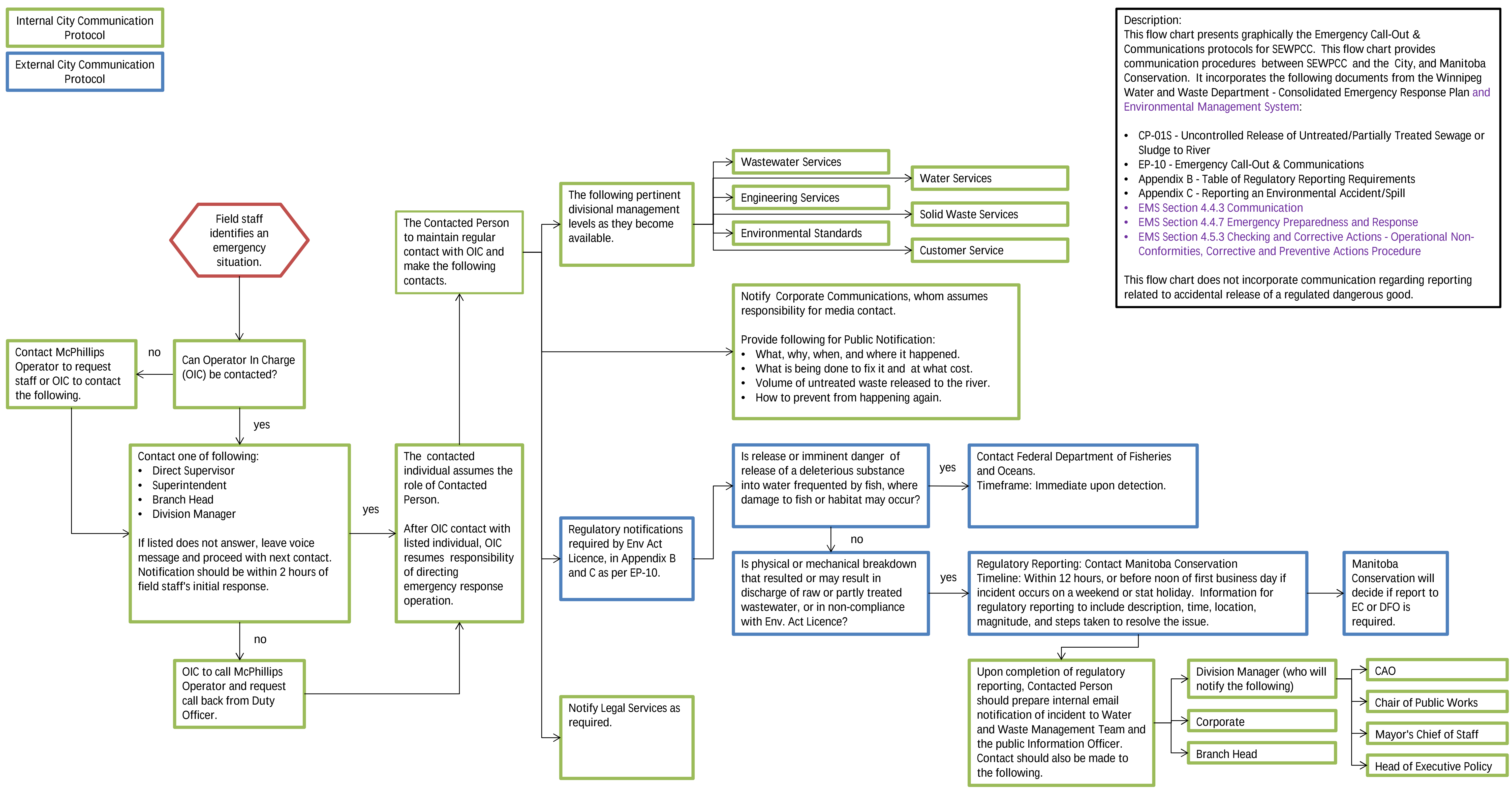


Figure 3-2
Flow Chart Summary of SEWPCC Emergency Call-Out and Communications Protocols

As noted by the colour-coding in Figure 3-2, much of the required communications are internal to the City. The flow chart illustrates the communication pathway from those staff closest to the event (i.e. “field staff”) all the way to City executive management and including the Mayor’s office.

Figure 3-2 also shows the external communication pathway to Manitoba Conservation and Water Stewardship and potentially to Environment Canada / Department of Fisheries and Oceans.

4 Environmental Management System and Quality Assurance Protocols - General Review and Summary

4.1 OVERVIEW

Continuing on with “non-technical” corporate system topics that may have relevance to the upset event, Section 4 speaks to environmental management systems and quality assurance protocols.

Section 4.2 presents City environmental management system protocols using flow chart graphics similar to those used in Section 3.2. These protocols are contained in the *City of Winnipeg Water and Waste Department Consolidated Environmental Management System Manual* (CEMSM). Given the context of this study, we have focused our review on CEMSM actions associated with system non-conformity, corrective and preventive actions, compliance procedures and internal communications procedures.

Again, Section 6 addresses how the City adhered to these procedures and protocols in response to the October 2011 event based on information available for this review.

4.2 FLOW CHART SUMMARY

Figure 4-1 summarizes CEMSM Section 4.5.3 that speaks to non-conformity and corrective and preventive actions. Like Figure 3-2, we created this flow chart based on our interpretation of the reviewed written material as no graphical information was available. As a result there is potential for some inaccuracy in the depicted flow of communications between parties given the parallel activities and lack of explicit information for how these parties are intended to communicate.

Neither Section 4.5.3 nor the broader CEMSM document explicitly define “operational non-conformity” or “non-compliance”. However, our understanding of Section 4.5.3 is that it is more applicable to “normal” operations rather than responding to an immediate emergency event, where the latter situation is covered by the CERP. For example - *standard operating procedure (SOP) “X” appears to be impacting the process and effluent quality in a negative manner and; therefore, SOP “X” needs to be corrected and revised*. Procedure 4.5.3 provides the mechanism for this identification and revision.

The colour-coding shown in Figure 4-1 indicates Section 4.5.3 does not require communications external to the City Water and Waste Department. This observation again suggests Section 4.5.3 is more applicable to normal operations rather than emergency response.

Figure 4-2 summarizes several CEMSM sections, developed using written reference information only, which span monitoring objective conformance (Section 4.5.1), evaluating compliance procedure (Section 4.5.2) and internal communications (Section 4.5.3). Again, our understanding of these sections is that they are generally applicable to the routine rather than emergencies and are intended to provide a mechanism

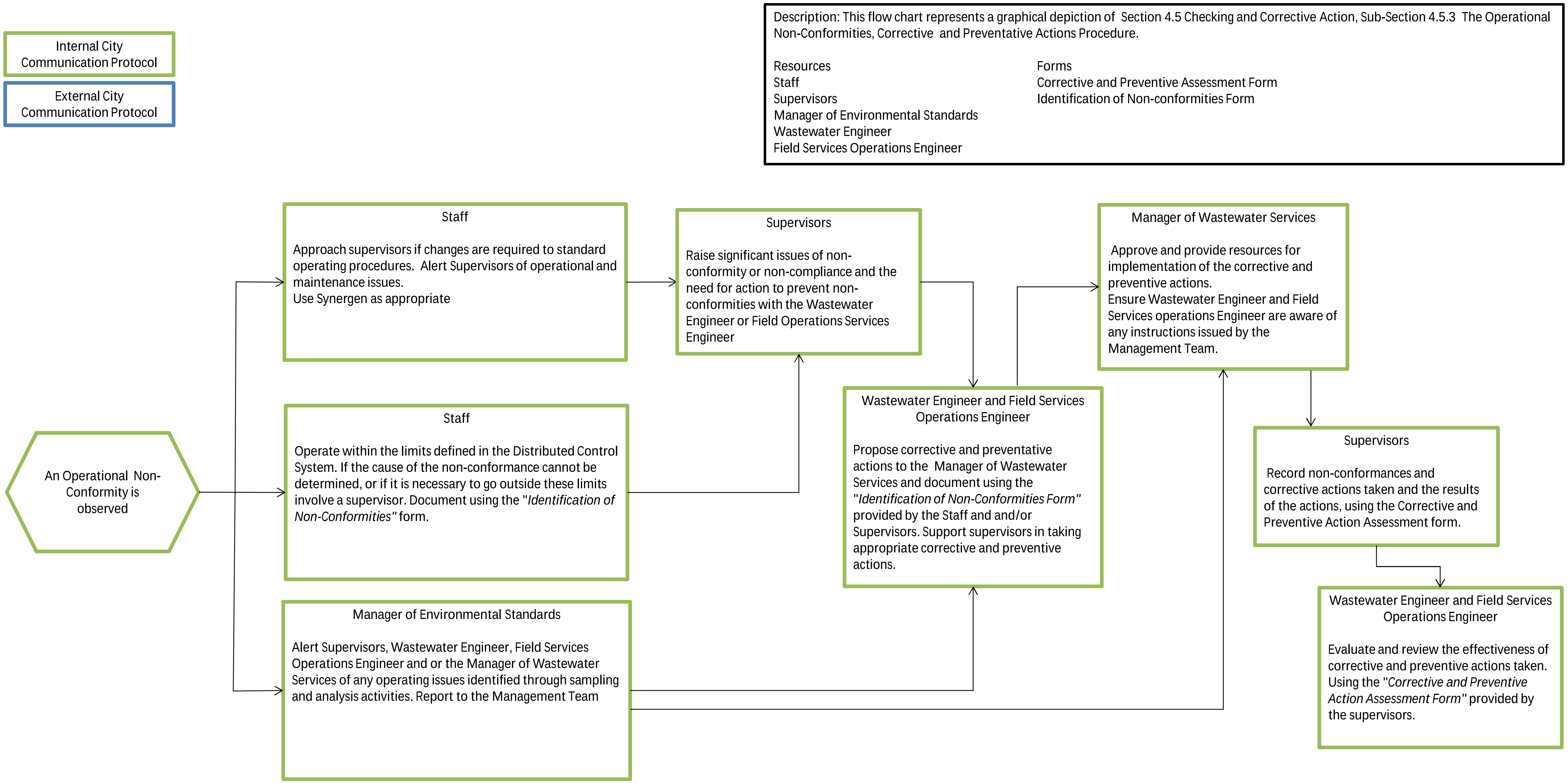


Figure 4-1
Flow Chart Summary of City Environmental Management System Section 4.5.3: Non-Conformity, Corrective and Preventive Actions

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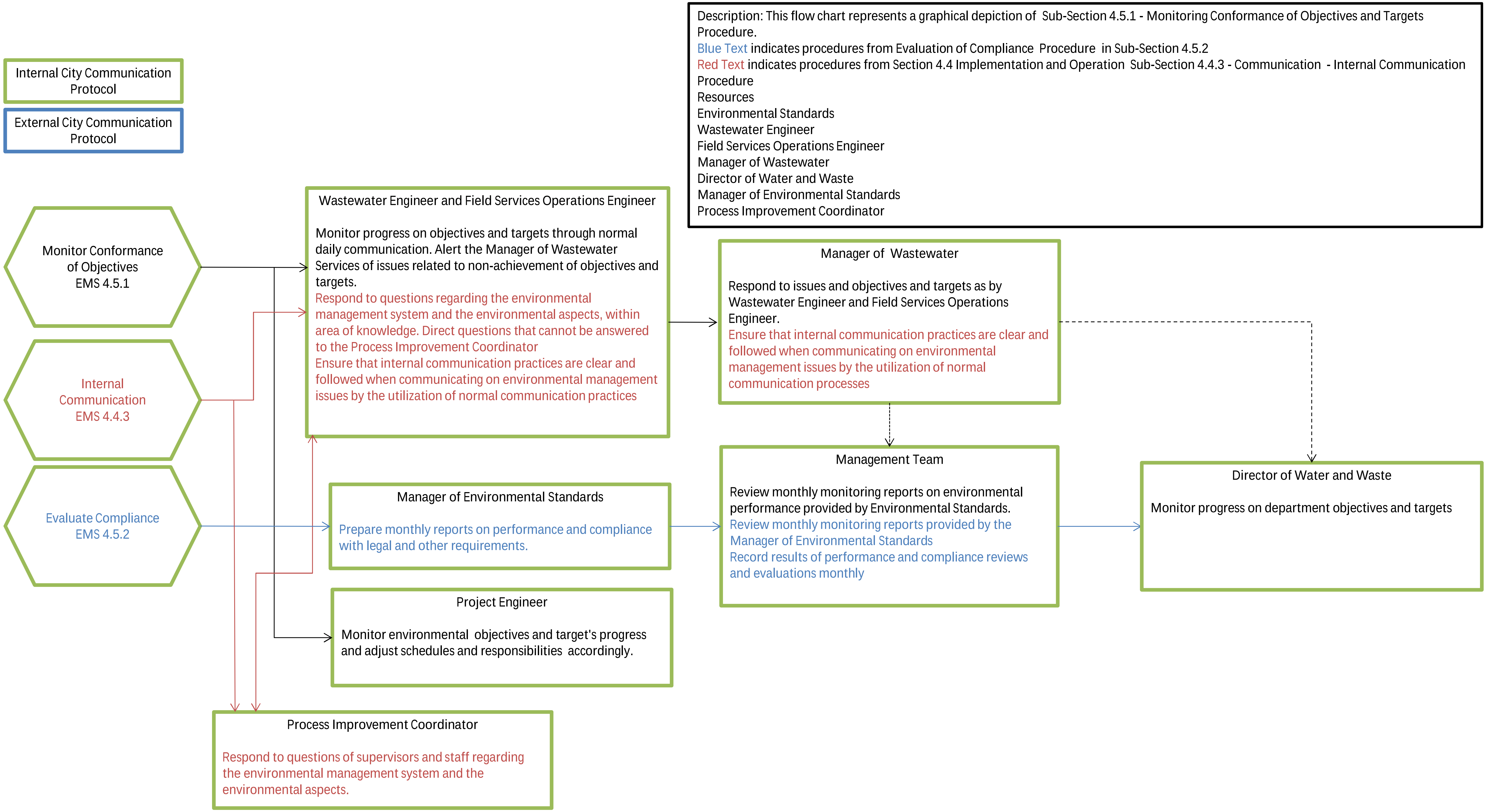

Figure 4-2
Flow Chart Summary of City Environmental Management System Section 4.5.1: Monitoring Conformance of Objectives and Targets, Section 4.5.2: Evaluation of Compliance, and Section 4.4.3: Internal Communication

\\S-sas-fs-01\projects\20124012\00_mb_cons_c_www\Advisory\01.00_Advice\DMS\Task_3\rpt_material\dnt_Section_4_figs_cm_ds.xlsx,Fig B,02/03/2012 for activity conduct. That said, the “normal daily communications” indicates that situations of an emergency nature would be captured in Section 4.5.3.

The colour-coding indicates all communications associated with these three sections are internal to the City.

5 SEWPCC - City Communication Protocol - General Review and Summary

5.1 OVERVIEW AND SUMMARY

Section 5 was intended to present SEWPCC-to-“city hall” (e.g. City Chief Administration Office, Mayor’s office, etc.) communication protocols for situations comparable to that of the October 2011 event that were not included in the CERP and CEMSM protocols. Similarly, the intent was also to present any additional communication protocols for individual organization units within the Water and Waste Department and city hall, again in the context of the October event. However, our review of Manitoba Conservation and Water Stewardship-supplied City information did not reveal any specific communications protocols related to these entities beyond those already presented in Section 3.2 and Figure 3-2.

6 Event Adherence Review

6.1 OVERVIEW

Sections 3, 4 and 5 summarized, using a flow chart format, essentially non-technical procedures or protocols adopted by the City in their Water and Waste Department *Consolidated Emergency Response Plan* and *Consolidated Environmental Management System Manual.* Using City-supplied information provided to Manitoba Conservation and Water Stewardship and made available to Associated Engineering, Sections 6.2 and 6.3 attempt to document how the City adhered to these non-technical protocols in response to the October 2011 SEWPCC event using annotated versions of the previously constructed flow charts. While this format provides ready display of City actions, the reader must recognize the completeness of information presented is constrained by the material provided for our review.

Sections 6.2 and 6.3 focus on City adherence to CERP and CEMSM protocols, respectively. Since these protocols are largely non-technical in nature and thus the City technical actions cannot be assessed in terms of adherence to them, Section 7 speaks to the City's overall technical response to the event independent of the CERP and CEMSM.

6.2 SEWPCC EMERGENCY RESPONSE PLAN

Figure 6-1 presents an annotated version of Figure 3-1 that documents the City response to the October 2011 event from the perspective of SEWPCC procedure CP-01S that is specific to the SEWPCC for "uncontrolled release of untreated / partially treated wastewater or sludge. We have limited the annotations in Figure 6-1 to those few technical items not contained in Figure 6-2, which provides a more comprehensive picture of communications relative to Figure 6-1.

In this regard, the City did initiate the following technical activities, noted in Figure 6-1, in general adherence to CP-01S:

- Advised Collection to divert wastewater flow away from the SEWPCC
- Conducted "repairs" to return to normal operations
- Collected data to establish quality and quantity of discharge (e.g. final effluent)
- Expanded routine water quality data collection program to determine event impact on the Red River.

Figure 6-2 shows an annotated version of Figure 3-2, which illustrates City communications from the time when the event was first noted. While we did not have access to available communications information (e.g. e-mail, telephone call logs, etc.) outside of what was provided to us via Manitoba Conservation and Water Stewardship, the following observations can be made regarding City adherence to communications protocols depicted in Figure 6-2:

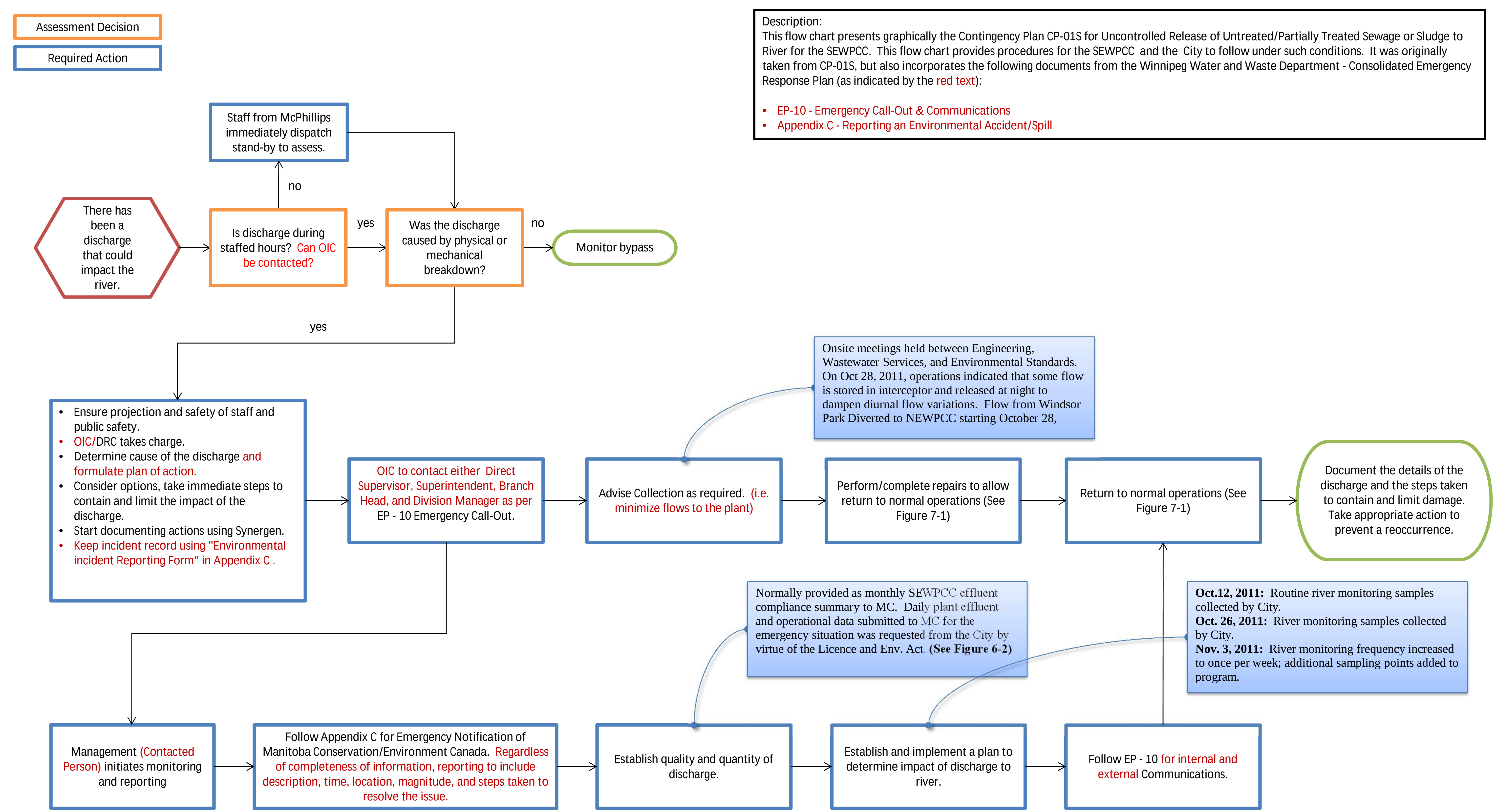

Figure 6-1
Annotated Flow Chart SEWPCC Emergency Response Plan for Uncontrolled Release of Untreated / Partially Treated Wastewater or Sludge per City Response to October 2011 Event

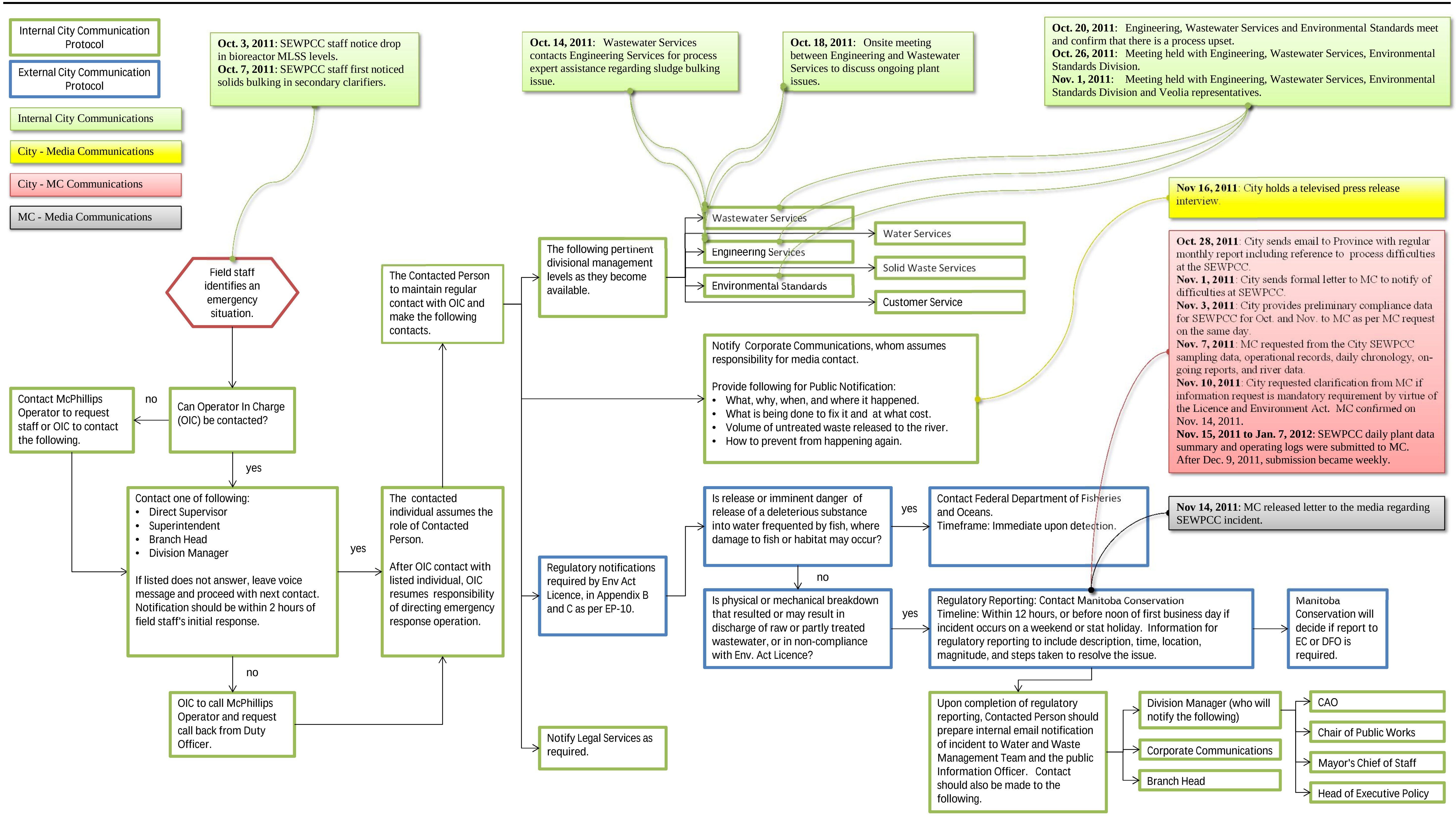

Figure 6-2
Annotated Flow Chart of SEWPCC Emergency Call-Out and Communications Protocols per City Response to October 2011 Event

- Although we do not know the exact of timing of some internal communications, the City did appear to adhere to its protocols in terms of contacting and engaging "pertinent divisional management" in terms of Wastewater Services, Engineering Services and Environmental Standards.
- The City held a televised press release interview, which presumably was intended to meet the intent of the "Public Notification" requirement of its procedures.
- The first City communication with Manitoba Conservation and Water Stewardship regarding the event was contained in a regular monthly report e-mailed to MC approximately three weeks after the event trigger. However, as noted in Figure 6-2, the SEWPCC Environment Act License requires Manitoba Conservation and Water Stewardship notification within twelve hours, or before noon of the next business day, if a "physical or mechanical breakdown" will result in discharge of untreated or partially treated wastewater or non-compliance with the license requirements. On the basis of information provided, the difference in reporting timeline appears to have been based on the City's interpretation of the License requirement (i.e. did not categorize the event as a "physical or mechanical breakdown").

6.3 ENVIRONMENTAL MANAGEMENT SYSTEM

As discussed in Section 2.2, the SEWPCC experienced a filamentous bulking event that resulted in degraded effluent quality for an extended period of time. Section 7 provides detailed discussion on how the City responded to this situation, but for the purpose of Section 6.3 it suffices to say that the City did not have in place a detailed procedure (e.g. standard operating procedure, SOP) for responding to such an event in October 2011. CEMSM Section 4.5.3 provides the mechanism for the City to develop and implement "corrective and preventive actions" (e.g. an SOP) to respond to a similar future event.

None of the information we reviewed suggested that Section 4.5.3 was "formally" activated in the fall of 2011 to develop such an SOP (e.g. submission of *Identification of Non-Conformities Form* and *Corrective and Preventive Action Assessment Form*) post-event. This situation explains why we could not present an annotated version of Figure 4-1.

As discussed in detail in Section 7, the City did respond to the event, apparently successfully, in terms of taking corrective action. Given the timeline of activities, available resources and need to physically respond to what was an emergency event rather than a normal operations situation, it would not be surprising if the City by early January (i.e. the extent of information available for this review) had not formally activated Section 4.5.3 to develop an SOP for responding to a future filamentous bulking event. Furthermore, we may simply have not been privy to internal City communications and activities in this context. Therefore, the question of whether the City adhered to Section 4.5.3 in terms of such an SOP is not readily answered within the constraints of this review.

We have not been provided information that can be used to assess the adherence of City actions in relation to Monitoring Conformance of Objectives and Targets (Section 4.5.1), Evaluation of Compliance (Section 4.5.2) and Internal Communication (Section 4.4.3). Therefore, we could not prepare an annotated version of Figure 4-2 for Section 6.

7 Event Response Review

7.1 OVERVIEW

Sections 4 through 6 considered the City's emergency response plan and environmental management system and how the City adhered to their requirements in response to the October 2011 event. As discussed previously, the context was largely one of communications and procedural mechanisms rather than technical actions. Section 7 now speaks to the City's overall technical response to the event independent of the CERP and CEMSM procedures. Section 7.2 focuses on technical choices available to the City and actions taken, with Section 7.3 specifically addressing the City's use of time in responding to the event.

7.2 CHOICES AND ACTIONS

Figure 7-1 presents a chronology of event observations and City actions from early October to the end of December, 2011. The line graph at the top of the figure, which shows final effluent TSS and TBOD concentrations and was presented previously in Section 2.2, helps to orient the reader along the time line. As noted in Figure 7-1, we obtained the information presented from daily logs recorded by SEWPCC staff, microbial analysis reports prepared by the City as well as an external laboratory, and an event chronology summary prepared by the City. The information presented should not be construed as, nor is it intended to be, exhaustive. Rather it serves to summarize key City observations and actions.

As shown below, from a *facility operations* perspective, City actions taken in response to the October event can be characterized under two broad headings: (i) process manipulations (PM) and (ii) external system activations (ESA). Table 7-1 describes the general purpose of these actions independent of any City-supplied information.

Process manipulations (PM):

1) return activated sludge (RAS) flow
2) waste activated sludge (WAS) flow / solids retention time (SRT)
3) influent wastewater flow via short-term storage in upstream interceptor or long-term diversion to NEWPCC
4) bioreactor oxygen supply feed purity / bioreactor vent gas oxygen level
5) primary effluent (PE) flow distribution

External system activation (ESA):

1) return activated sludge (RAS) chlorination
2) post-bioreactor mixed liquor (ML) polymer addition
3) biomass seeding from NEWPCC
4) chemically-enhanced primary treatment (CEPT)

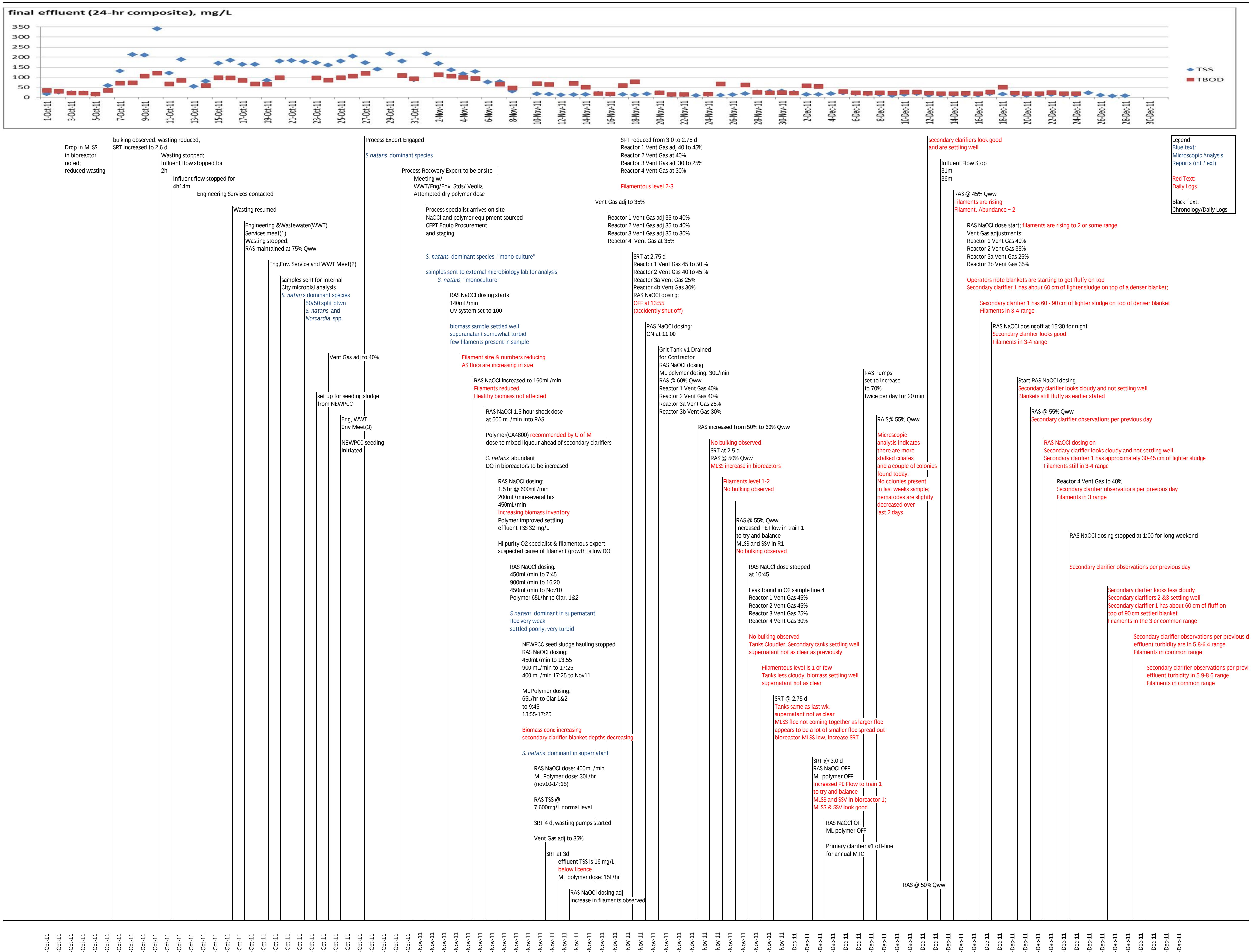

Figure 7-1
Chronology of Event Technical Observations and Actions

PMs 1, 2, and 4 and ESA 1 and 2 are typical actions recognized in facility operations literature (e.g. Water Environment Federation, 1990) in responding to filamentous bulking events. PMs 3 and 5, as well as ESA 3, were additional action options available to the City given their specific infrastructure. We understand that the City put in place the equipment needed for ESA 4, but it was not used in response to the event at least during the time line of this review.

In general, the facility operations actions used by the City can be considered reasonable choices in light of typical industry responses for filamentous bulking events. Furthermore, as noted in Water Environment Federation (1990), solving problems quickly and effectively can be challenging and may require external assistance. Figure 7-1 notes that a “process expert was engaged” on October 28, presumably in this context, and reflects a good choice by the City at least conceptually.

PM 1, 4 and 5 can produce what are described as “quick, mild results” and the effects of ESA 2 can be quickly evident (Water Environment Federation, 1990). Alternately, PM 2 actions, because of the time scales involved, may take several days for results to become evident.

The City used PM 3, via wastewater storage in the interceptor, to even out the diurnal flow and loading peaks to the facility. To further reduce flow and loadings, the City also diverted wastewater flow from the Windsor Park development to the NEWPCC, which appeared to reduce the total 24-hr flow arriving at the SEWPCC by about 3 to 4 ML/d.

Although not an action specifically mentioned in literature reviewed for this study, the City invested notable effort seeding the SEWPCC bioreactors with biomass trucked from the NEWPCC (i.e. ESA 3). The actual effectiveness of this action is difficult to gauge, particularly if the fundamental cause of the bulking event has not been removed.

Of particular note is ESA 1. Use of oxidants, such as chlorine or hydrogen peroxide, is arguably the most common short-term response / remedy to a filamentous bulking event regardless of its causative factors. The thin filaments extending from biomass flocs are exposed directly to these oxidants, whereas most of the floc-forming microorganisms reside within the flocs and experience a lower chemical dose because of diffusional resistance (Seviour and Nielsen, 2010). As a result, the filamentous organisms are selectively killed over the floc-forming organisms.

There are a variety of factors that impact chlorination effectiveness. However, the City appears to have made good choices in this regard. For example, the selected chlorine dosing point (i.e. the RAS line) was most appropriate for this type of facility, which helps to ensure good mixing of chlorine with the biomass while largely avoiding organic material contained in the influent wastewater itself and whose oxidation would reduce the filament control efficiency (Grady et al., 1999). In addition, it appears that the City generally added chlorine to the RAS continuously. This dosing approach helps to ensure the entire biomass is exposed to chlorine for a sufficient daily duration and avoids a situation where significant filament growth occurs between discreet dosing periods. Finally, recorded City data show the applied chlorine dose concentration was typically in the range of 3 to 4 kg/t VSS – d within 10 days of the start of

RAS chlorination. These values fall within the typical 2 to 10 kg/t VSS – d range reported in Grady et al. (1999). Although there were some short-term, high-concentration "shock" dose events, the continuously applied dose value may have been somewhat lower during the initial days of RAS chlorination based on the recorded sodium hypochlorite flow rate data. This situation may have reduced the effectiveness of RAS chlorination during this initial period.

Once other actions were initiated, as shown in Figure 7-1, staff also attempted to fine-tune them (e.g. wasting rate, applied mixed liquor polymer dose) through the remaining days and weeks of 2011 following their implementation. There is a danger of making too many changes at once, or too frequently, but presumably the process expert engaged by the City provided staff guidance in this regard.

From a *facility monitoring* perspective, the City recognized the importance of identifying the dominant filamentous organism(s) that caused the bulking event. As discussed in Section 2.2 and highlighted in Figure 7-1, the City used both internal and external resources to accomplish this end. The information generated (i.e. identification of the low DO filamentous organism *S. natans*) ultimately contributed to some City actions (i.e. PM 4, 5) intended to eliminate / mitigate any low DO condition in the bioreactors. The City then implemented more rigorous monitoring of bioreactor DO levels, in all three stages of each bioreactor rather than the typical single point DO measurement, presumably to help inform its PM 4-related oxygen manipulations. Simultaneously, the City continued its microscopic examination of the biomass to monitor the microbial population and the eventual shift of an *S. natans*-dominated biomass to one more typical of normal facility operations; the latter apparently defined by what was observed at that time in NEWPCC biomass samples.

The City also continued to monitor other indicators of biomass settleability (e.g. SVI, secondary clarifier sludge blanket thickness) as well as effluent quality. All of these monitoring actions were appropriate activities given the nature of the upset event. In addition, continuing microscopic biomass analyzes provided insights into RAS chlorination effectiveness since their findings can provide an early indication of filament control ahead of improved biomass settleability (Water Environment Federation, 1990).

As noted previously, ESA 2 (post-bioreactor mixed liquor polymer addition) is a fairly common action in response to filamentous bulking events. Chlorinating biomass tends to produce a somewhat turbid effluent because of its physical effect on the cells (Water Environment Federation, 1990). ESA 2 can help mitigate the situation by helping to flocculate the dispersed solids. At the same time, regulator microscopic examination of the biomass can help to avoid situations of over chlorination that can increase effluent turbidity and drive the need for polymer addition.

7.3 USE OF TIME

Figure 7-1 indicates that the first sign of a potential problem at the SEWPCC was recorded by City staff on October 3(i.e. reduced bioreactor MLSS levels), with sludge bulking recorded as an observation on October 7. At the facility level, the City responded immediately with PM 2 actions (WAS / SRT manipulations), but did not implement ESA 1 (RAS chlorination), the primary response to a filamentous bulking event, until November 4. Love and Bott (2000) spell out the situation succinctly: "… when a filamentous bulking event is first observed, the operator can *immediately* [emphasis added] begin chlorinating the activated sludge for temporary control of filamentous bacteria so the sludge settling can be improved and effluent deterioration is avoided". The urgency in responding to these events is magnified in a facility like the SEWPCC where high microorganism growth rates, encouraged by the short biomass SRT operating condition, allow a rapid shift in microbial population in response to a trigger event. As shown in Figure 7-1, within three days effluent TSS levels increased from 15 mg/L to over 200 mg/L. Effluent TSS concentrations remained comparably elevated until about November 3, the day *before* the City started RAS chlorination. By mid-November final effluent TSS and TBOD concentrations were generally back to typical values, as were those for fecal coliform and E. coli (Figure 2-7).

Based on the post-November 4 data and industry experience in general, the City's response time in initiating RAS chlorination likely contributed to the extended period where the final effluent was out-of-compliance with License requirements. Part of the reason for this response time was that the City did not have in-place a RAS chlorination system. This is not the only explanation, as the City was able to source and order sodium hypochlorite (i.e. chlorine), and the pumps and piping needed for a temporary system, on November 2 and begin RAS chlorinating only two days later on November 4. The explanation may be due, in part, with the effort expended in seeding the bioreactors with biomass trucked from the NEWPCC. This action was initiated on October 26 and continued until November 9. The resources needed for this effort may have impacted the City's ability to implement RAS chlorination earlier. Alternately, it may have unintentionally diverted efforts away from potentially more effective actions. However, we acknowledge these suppositions are just that and based only on information reviewed for this study.

A second oddity in the time line of City response is the initial collection and analysis of biomass samples, which did not occur until October 21 and approximately two weeks after sludge bulking was first observed. As discussed in Section 2.4, these samples were analyzed by the City's own internal Analytical Services Branch. Given the importance in identifying the dominant organism(s) responsible for bulking events, in terms of identifying solutions, the delay in this effort given the City's own capability was unexpected.

Alternately, by October 23 the City was aware that *S. natans* was the dominant filamentous organism and had recognized its potential association with low bioreactor DO conditions. Evidently in response to this information, the City made a timely bioreactor vent gas manipulation (i.e. PM 4) shortly afterwards on October 25, again on November 11 and multiple times afterwards. We assume that adjusting the vent gas oxygen set point concentrations was an attempt to more evenly distribute oxygen supply to the various bioreactor trains. However, the City did not begin monitoring the DO in each stage of the bioreactors until November 17, based on the information available for review. This was unexpected given the importance of bioreactor DO data to inform the manipulations.

We also understand that the City attempted to increase the oxygen content of the feed gas beyond the typical 90% value; however, we do not know the exact timing of this type of manipulation or its extent.
All of these noted actions required a decision. Given the timeline of internal communications and meetings shown in both Figure 6-2 and Figure 7-1, it appears that some decisions needed were controlled by a schedule of communication that, by some measures, did not respond to the required urgency. Some of the

observations noted above on the City's apparent extended use of time in responding to the event suggest a number of deficiencies in City systems and protocols. Section 8 further explores these apparent gaps.

8 Gap Analysis

8.1 OVERVIEW

Set in the context of the probable event trigger identified in Section 2, and in light of the findings discussed in Sections 6 and 7, Section 8 offers observations and insights related to gaps in the SEWPCC operating procedures, the emergency response plan, infrastructure, and communications. There are many interconnections among these subject areas and, as a result, we have presented a holistic discussion in the single Section 8.2.

8.2 OBSERVATIONS AND INSIGHTS

An obvious place to start with the commentary is how the City responded to the filamentous bulking event. Clearly, there were gaps that stretch across several subject areas:

1) Based on the City response to the October event it seems clear the City did not have in place a detailed technical procedure, and associated communications/decision-making protocol, for responding to a filamentous bulking event *once identified*. Given the relatively large size of the SEWPCC, the reality that the majority of WWTFs experience bulking events, and the closeness to which the SEWPCC may be operating relative to its intended design capacity (e.g. Wardrop / MacLaren, 1993), the lack of a detailed response procedure is a notable gap in City procedures.

2) Related to 1), the City did not have RAS chlorination infrastructure in place at the time the event was triggered. Again, this situation appears as a notable gap for reasons similar to item 1) and given the predominant role that selective oxidation, such as that provided by RAS chlorination, has in the wastewater industry for responding to such events. The City also did not have in place a polymer dosing system at the time. However, its need is less obvious and one that the City can best gauge given its experience with the fall 2011 event.

Another important context to consider is how the City might have identified a developing filamentous bulking event, which could then trigger its response to the event as discussed above. Again, there are several gaps to consider:

3) Broadly speaking, filamentous bulking is a complex technical subject from many perspectives: its causes, the organisms involved, identifying specific organisms, and effective long-term solutions. Regular and routine microscopic analysis of biomass samples may provide some advanced indication of a developing filamentous bulking event. There are many challenges and limitations in using microscopic methods to identify *specific* filamentous organisms (e.g. see Seviour and Nielsen, 2010) and the conduct of such examinations requires a skilled and experienced analyst. Alternately, as noted by the Water Environment Federation (1990), using a microscope to identify filamentous organisms as a major microbial *group* among others (i.e. protozoa, rotifers), and their

relative abundance, can provide useful information for facility operators and is a practical skill that can be developed by such staff.

In this context, the City appears to have made two choices that may have prevented it from noticing a filamentous bulking event was developing. First, the City Analytical Services Branch (ASB) evidently had the capability to conduct filament identification analysis. However, based on information available for review, it appears that the ASB was not conducting routine biomass analyses as part of its regular duties for the SEWPCC. Second, no information we reviewed suggested that routine microscopic examination of biomass was conducted on-site by SEWPCC staff as part of its normal duties. It cannot be said with any certainty that had the City had such monitoring in place ahead of the October event that it would have been able to see it coming and thus have responded sooner and more effectively to it. At the same time, the converse cannot be ruled out either.

For reasons similar to those for items 1) and 2), we view the lack of regular microscopic examination of SEWPCC biomass, particularly at the SEWCC staff level, as a notable gap in City procedures.

4) Related to item 4), a broader gap was the apparent lack of a technical procedure that defined a parameter, or set of parameters, and assigned measurable values, which the City could have used to identify a developing filamentous bulking event and subsequently initiate the response procedure. This technical procedure could have had an associated communications protocol to guide staff actions and decision-making.

9 Conclusions and Recommendations

9.1 CONCLUSIONS

The key conclusions drawn from this review include:

- The SEWPCC upset of October 2011 was a filamentous bulking event that ultimately led to a significant compromise in final effluent quality over an extended period
- The event was likely triggered by low mixed liquor DO levels in the bioreactors, the cause of which is uncertain but probably involves multiple factors
- It appears unlikely that the October upset event was the result of a toxicant(s) discharged to the City wastewater collection system
- The technical actions taken by the City in response to this event were generally appropriate given its hypothesized underlying cause
- The timeline of these actions demonstrated some inefficiency in the use of time in responding to the event that likely contributed to the duration, and possibly extent, of final effluent non-compliance
- Several choices, in terms of regular monitoring at the SEWPCC as part of normal facility operations, may have compromised the City's ability to recognize, and thus respond quickly to, a developing bulking event
- The review illuminated a variety of deficiencies, or gaps, in City systems, protocols and infrastructure
- In terms of existing protocols and procedures, which are largely non-technical with a communications focus, the City did appear to adhere to at least their general intent in some specific instances, based on the information made available for this review. More extensive conclusions on this point cannot be drawn from the information Manitoba Conservation and Water Stewardship provided to our team for this review.

9.2 RECOMMENDATIONS

The key recommendations to mitigate similar, future events that are important for consideration include:

- Prepare a technical procedure for *identifying* the development of a filamentous bulking event and an associated communications protocol to guide staff actions and decision-making at the SEWPCC
- Conduct regular microscopic evaluations of biomass on-site at the SEWPCC
- Develop a detailed technical procedure for *responding* to a filamentous bulking event, which should also include a communications/decision-making protocol at the SEWPCC
- Provide appropriate RAS chlorination infrastructure at the SEWPCC to allow staff to respond quickly and efficiently to similar events
- Assess the worth of the polymer dosing action based on the event experience; if valuable, provide an appropriate system at the SEWPCC for responding to future events

- Revise the *Environment Act* License notification requirement (i.e. "physical or mechanical breakdown") using appropriate language with the intended outcome being timely notification that is independent of hypothesized or actual cause of a non-compliance situation.

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