# Realities of Stormwater Quality

## Singapore vs Small Town Australia

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**KEYWORDS**

Storm water, Waste water, TOC/DOC/Turbidity, COD/CODf/solids

## Abstract

**Storm water means many things to different people. From a quality as opposed to a quantity perspective things become less complex.**

For the purposes of this paper the narrow definition of storm water sourced from man made surfaces, such as city streets and public spaces, entering a dedicated storm water piping /channeling system will be considered.

Man made storm water systems generally run directly to the ocean, to rivers or other publicly accessible ponds/wetlands. It is generally assumed that the water is fit for this purpose. The question posed here will be whether this is really the case and what risk is being accepted using current design and monitoring methods.

The data sets available for flow in storm water systems tend to be comprehensive, while the data sets providing composition or quality data are at best patchy and limited to composite or the occasional grab sample. The lack of significant real time data on water quality has made it hard to evaluate the appropriateness of existing storm water practice and to quantify the inherent risks.

This is not an approach which will be sustainable in the future with an increasingly litigious society with higher and higher expectations with respect to public use of waterways.

This paper focuses on providing a window into what really occurs in storm water drains in real time from a water quality perspective. The data presented will allow a determination of the best management model based on the realistic risks involved for the particular receiving system.

Two separate storm water system case studies will be covered. The first compares multiple storm water channels dealing with run off from Singapore's city areas. Comparisons can be made between the water quality coming from different drains and within one drain over time. The intent being to allow evaluation of the suitability of the current practice of direct discharge to the ocean.

The second involves a longer term study on a storm water system coming from Mannum in South Australia. Although Mannum is a small town, the drain enters the Murray River just 20 metres from a major intake for Adelaide's drinking water. Specific work to detect and quantify hydrocarbons was part of this project.

# Introduction

Storm water sourced from man made surfaces such as city streets and public spaces entering a dedicated storm water piping/channeling system generally run directly to the ocean, to rivers or other publicly accessible ponds/wetlands. It is generally assumed that the water is fit for this purpose. Due to the high cost of sampling and the perceived low risk of such waters, little data is actually available to confirm whether or not this is the case. This is not an approach which will be sustainable in an increasingly litigious society with higher and higher expectations with respect to public use of waterways. Events known to occur as a result of less than clean storm water include the litigation by oyster farmers in the area around the Opua oyster farms. In that case it was sewer overflows. Unexplained receiving system biology die-offs, algal blooms or shellfish contamination occur and due to lack of evidence as to the source they are generally forgotten about once the media has finished with them. Many cases of long term build-up of toxins exist which are actually point source related however lack of real time data fails to identify this and the source is not tracked down.

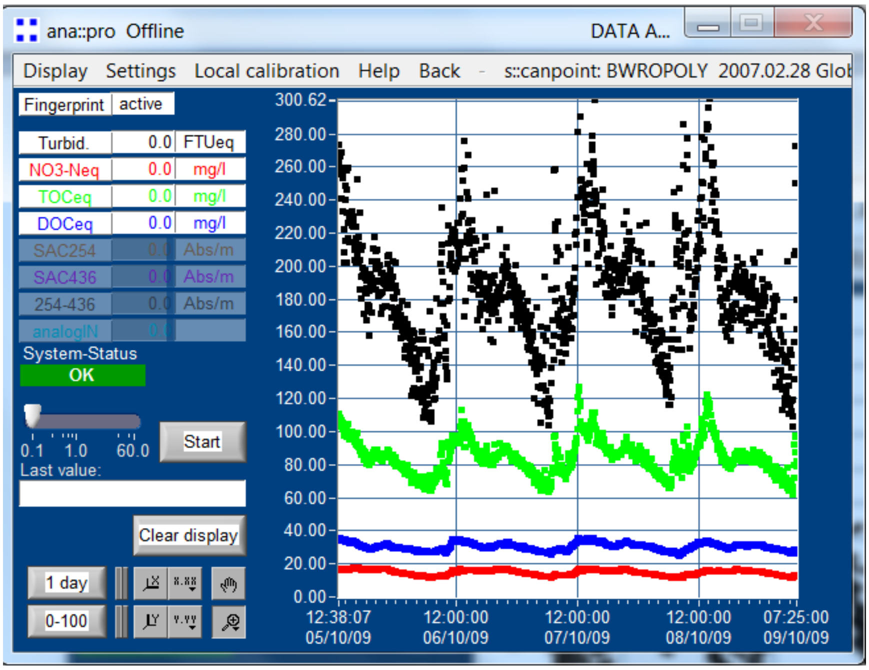
The photo of a local creek along the boundary of an industrial area is an example of such contamination. Regulation and policing of regulation of such storm water is impossible without continuous measurement of suitable parameters and knowledge of what these parameters mean for the receiving environment.

In addition to general public concerns over access to safe swimming/recreation and healthy biota in the ocean, rivers and wetlands there are rising concerns around the use of such waters for drinking. With water availability becoming of greater concern worldwide as populations increase and general demand for water increases, the use of previously untapped water sources such as storm water becoming of greater interest. Naturally the quality of the water and the risks involved in it's use becomes of the focus of regulators.

Storm water is by it's nature relatively unpredictable in both it's timing of arrival and the quantities involved. Similarly the quality of the water depends very much on the catchment it comes from and the risks of deliberate or accidental discharge of unwanted contaminants into that catchment. To find out more about the potential risk involved in storm water, a number of authorities around the world have initiated studies of one type or another. This paper utilizes data obtained from a study run over shorter time frames in a series of storm water channels carrying water away from the central city areas of Singapore and a longer term study from a storm water drain in South Australia discharging to the Murray River. Both studies used in channel mounted full spectrum UV/Vis spectrophotometers from s::can of Austria to provide both spectral data and calculated carbon and solids equivalents.

One of the initial problems encountered in both of these studies was the reporting parameters. The carbon and solids based parameters in water are traditionally reported in terms of TOC, DOC and turbidity while waste water is reported in COD, CODf and Solids terms. The question was, when does storm water become wastewater? Due to the perception that storm water was clean, DOC/TOC/Turbidity were chosen.

To assist with this determination a reference for both “clean” and “dirty” water is needed. For the “dirty water reference”, a spectral data set from the inlet of a municipal waste water treatment plant was re-run offline using the same software model as used on both the Singapore storm water channels and the Murray River Storm water channel. Values were displayed as TOC, DOC and turbidity values. This is seen in Image 1. A second set from a river source used for drinking water acts as a “clean” data set.



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| SAC254 | 0.0 | Abs/m |
| SAC436 | 0.0 | Abs/m |
| 254-436 | 0.0 | Abs/m |
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**Image 1:** 4 days of raw wastewater influent data from a municipal WWTP inlet channel

Image 1 shows that the levels of DOC as indicated by the plot above is 30 to 40mg/l. While the algorithm used here is designed for river water so will not be absolutely accurate without some local calibration the key thing to note is that it is using the same algorithm which is used on the storm water drains. This means there is a good degree of relativity between the data sets.

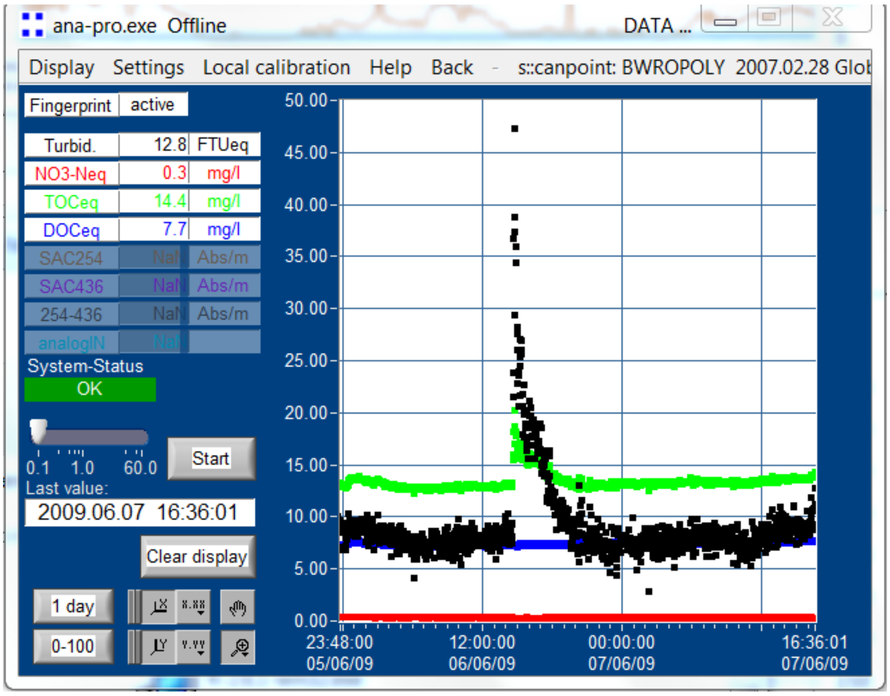

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**Image 2:** Murray River - Mannum South Australia

Image 2 is the second reference point for “clean” water. Data is from the Murray River from 2009 at the intake to one of Adelaide’s water treatment plants. This water is considered relatively contaminated by drinking water source standards. This is again using the same algorithm on the spectral data. Note also the lack of a shift in DOC during a high flow event which saw a significant turbidity increase caused by localized rain and subsequent runoff from the relatively barren land in this part of the country.
After the recent floods the DOC in the river has risen from the 7.7 mg/l seen here to around 25 to 30mg/l due to the contaminants from multiple upstream sources. The water treatment plants are struggling to deal with the loading and applying alum loads virtually unheard of in NZ.

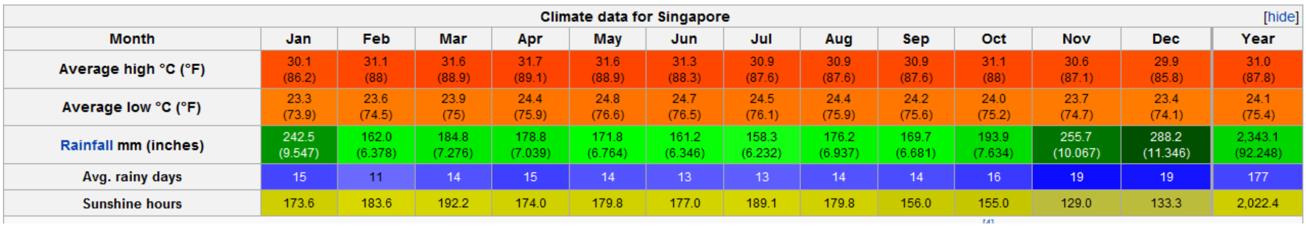
We can safely say that waters showing DOC’s using this algorithm above 25mg/l are seriously dirty. A brief and non scientific study in the office of the general public’s perception of storm water indicated that using a 0 to 10 scale of dirtiness with 10 being raw sewage, river water was expected to be 1 and storm water between 2 and 4. So what is reality?

# Case Study 1

## Singapore Storm water

The Republic of Singapore is essentially a very densely populated city off the coast of the Malay Peninsula.

Singapore has a land area of approx 700 sq km making it approx 23 by 30Km with a population of close to 5 million. I.e. the entire of NZ's population plus some packed into an area about the same as the old Auckland central area. The dense population and significant infrastructure to support it results in very large paved areas with a distinct lack of porous areas to absorb storm water run off. Combine this with tropical rainfall conditions consisting of sudden heavy showers and a total rainfall of around 2.5 meters per annum and you have very rapid flow increases with large volumetric water flows for short periods.



Climate data for Singapore [hide]

| Month | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Average high °C (°F) | 30.1 (86.2) | 31.1 (88) | 31.6 (88.9) | 31.7 (89.1) | 31.6 (88.9) | 31.3 (88.3) | 30.9 (87.6) | 30.9 (87.6) | 30.9 (87.6) | 31.1 (88) | 30.6 (87.1) | 29.9 (85.8) | 31.0 (87.8) |
| Average low °C (°F) | 23.3 (73.9) | 23.6 (74.5) | 23.9 (75) | 24.4 (75.9) | 24.8 (76.6) | 24.7 (76.5) | 24.5 (76.1) | 24.4 (75.9) | 24.2 (75.6) | 24.0 (75.2) | 23.7 (74.7) | 23.4 (74.1) | 24.1 (75.4) |
| Rainfall mm (inches) | 242.5 (9.547) | 162.0 (6.378) | 184.8 (7.276) | 178.8 (7.039) | 171.8 (6.764) | 161.2 (6.346) | 158.3 (6.232) | 176.2 (6.937) | 169.7 (6.681) | 193.9 (7.634) | 255.7 (10.067) | 288.2 (11.346) | 2,343.1 (92.248) |
| Avg. rainy days | 15 | 11 | 14 | 15 | 14 | 13 | 13 | 14 | 14 | 16 | 19 | 19 | 177 |
| Sunshine hours | 173.6 | 183.6 | 192.2 | 174.0 | 179.8 | 177.0 | 189.1 | 179.8 | 156.0 | 155.0 | 129.0 | 133.3 | 2,022.4 |

**Table 1: Climate Data for Singapore**

The rain water channels are hydraulically designed to manage these short sharp flows however the requirements for flood prevention which is a major problem for Singapore limits the options for local retention. Discharge to the environment is via expensive and comprehensive reservoir systems and river weirs to attempt to manage water quality. Singapore's national water agency PUB commissioned a study of storm water quality in major drains from the city with the intention of establishing how reality matched the grab and composite data used historically for storm water management planning. The study was undertaken by Pipeline Services Singapore branch under Stewart Hine. An s::can full spectrum UV/Vis spectrophotometer was provided by DCM Process Control for the study which resulted in data blocks from 10 of these storm water drains targeted at capturing large flow events.

**Image 3:** Typical drain structures

Singapore Data

The data sets from the Singapore storm water channels cover varying time frames as the length of the study was preset and storm water events were not predictable. In general though, most channels experienced an event or two during the period monitored.

In addition to the UV/Vis spectral data, grab sampling with subsequent lab testing was done for faecal coliforms and nutrients such as ammonia, TKN and phosphorous. The limited lab sampling data limits conclusions on these aspects however the general indication is that the coliform counts follow the turbidity trend and the dissolved nutrients follow the DOC as indicated by the UV/Vis data.

While detailed flow data was not available, observation indicated that the turbidity followed peaks in flow while DOC was unrelated to these flow peaks particularly where multiple rain events occurred in a short time frame.

**Image 4:** Bishan storm water channel was monitored over a 12 hour period.

No significant event occurred at this site during the 12 hours with DOC in green in image 2 being very close to that seen in the raw wastewater in image 1 at between 25 and 30mg/l. Coliforms were low and nutrients such as N and P were similar to those in treated wastewater rather than raw wastewater. Ie approx 4 mg/l and less than 0.5 mg/l respectively.

**Image 5:** HC3

HC3 was monitored for a period of 4 hours as some flow events were present early in the data set. Turbidity events are clear although small when compared to some catchments, with DOC being almost unchanged by the shift in the flow. Small flow shifts did however seem to affect the amount of suspended material which probably reflected the hydraulic forces on solids already present in the bottom of the channels as flow velocity increased rather than new material entering the channels from the storm water catchment.

**Image 6: HC2**

HC2 was monitored for a 2.5 hour period just in time to catch a relatively significant flow event. Here it is clear that substantial amounts of solids is being washed into the channel system with turbidity levels going from almost zero to above 55 NTU eq in a matter of minutes. There are two secondary turbidity surges due to small rainfall events an hour or so after the main event. The DOC and other soluble fraction trends show a delayed rise and very tapered drop off unlike the solids. This characteristic is common as the run off dissolves both soluble solids and brings in dissolved organics from the catchment. This is the commonly perceived pattern for storm water flows.

**Image 7:** HC16

HC 16 saw a number of rain events in the 7 hour monitoring period. The showery conditions shows how rapidly the flows rise and fall and the total lack of correlation between the turbidity and the DOC where multiple flow events occur. The DOC lags the turbidity, by several hours however goes through a doubling and halving of concentration during these few hours.

**Image 8:** HC23

Here HC23 was monitored for a 3 hour period during which no major rain event occurred. The flow in the channel was however quite high from previous rain in the catchment. Here the turbidity and the DOC correlate well due to the difference in hydraulic conditions that occur under this condition. The comparative levels of DOC however exceed by quite a margin that expected in raw sewage. Ie about a 14 on a scale of 1 to 10!

**Image 9:** HC23

This second monitoring period in HC23 targeted at catching a flow event covered just over 6 hours. The correlation between turbidity and DOC completely breaks down and the lagging DOC trend seen at other locations is re-established. Note that the DOC trend while generally lagging is relatively unpredictable without detailed modeling of the catchment and it's DOC sources.

**Image 10:** HC25.

This storm water channel has DOC levels in the same region as most previous channels at around 25 to 30mg/l at the start of the 6 hour monitoring period. Flows from previous rain just prior to the start of the monitoring saw a steady rise in DOC to around 50mg/l as the turbidity dropped to around the same level then had both rise together over several hours to values around 70 or 80. If we compare this to the plot of raw wastewater at below 40mg/l the levels of contamination become evident. The shape of the trends implies material coming in from sources with quite high natural DOC and turbidity sources. Although no faecal coliform data is available from this site, it has an average ammonia level of several mg/l with composites showing peaks above 10mg/l.

Note that once the next rain surge occurs, the turbidity rises yet the DOC immediately drops. A pattern of multiple rapid showers passing across this catchment is seen in the turbidity and reflected accurately in the DOC. It is likely that this channel has ingress under normal conditions from a highly contaminated possibly commercial/industrial source and that the storm water effectively dilutes this material.

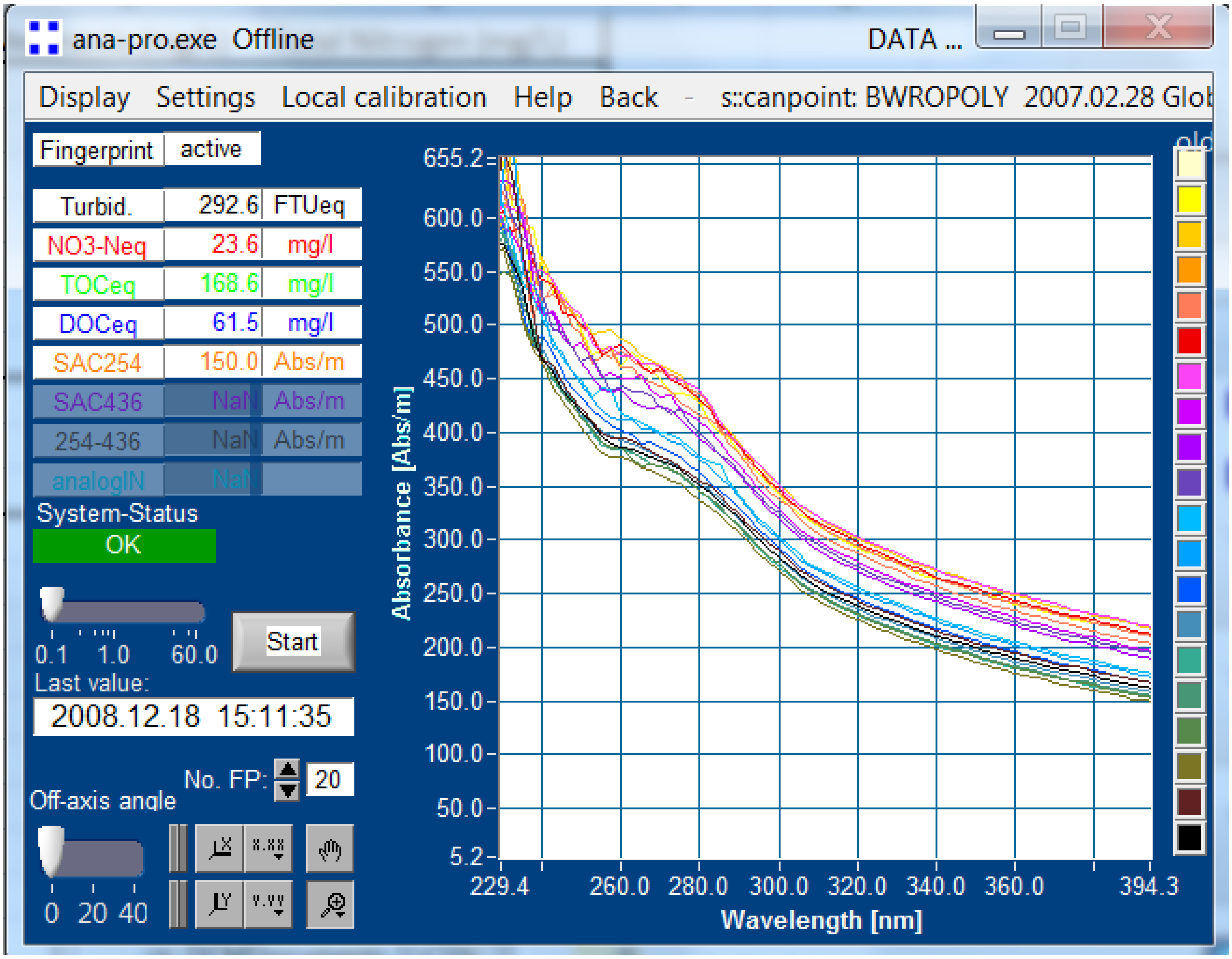


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**Image 11:** Spectral data from HC25

Spectrally significant increases in groups of organics absorbing around 260 to 280 nm are evident which is generally a good indicator of proteins. The source may involve an abbatoir or food factory which may have a leak into the local groundwater.

So what has the study told us?

One of the main effects of the relatively short monitoring study has been a recognition of the differences between assumed organic/turbidity loadings and their causes and reality.

The water in these channels generally approaches organic loadings similar to raw municipal sewage although the ammonia and coliform levels are well below those seen in such sewage. The fact that in most cases the levels rarely drop to those typical in a natural receiving water such as the Murray River reference of 7.7mg/l indicates that some degree of organic treatment is required to prevent damage to the environment. What is clear is that a simplistic diversion on first flush principle will have an effect only on the coarse and relatively rapid settling solids suspended by these storm water events. The effect of first flush separation on organics contamination is therefore likely to be negligible.

Singapore has dealt with this high organic loading by working on all factors involved. Flood prone areas often providing cheap land for industrial plants has had significant modification ranging from land reclamation works to raise ground levels compared to water tables and the building of major improvements to storm water control levees and flood barriers. The reduction in inundation events into commercial/industrial buildings has seen a drop in contamination of storm water during rain events. Many new water quality management ponds utilizing natural biological systems and incorporating public access have been built. These include features such as fountains acting as aerators and other aspects to enhance biological removal of nutrients while providing a positive recreational environment. Receiving rivers have had weirs placed across them to create treatment opportunities prior to discharge to the sea. Occasional rechecks of the on line data in these catchments is intended to check performance improvements over time.

# Case Study 2

## Mannum South Australia

The second study involves a longer term project to manage a storm water system coming from the town of Mannum in South Australia. Although Mannum is a small town, the town's main storm water drain enters the Murray River just 20 meters downstream from a major intake for Adelaide's drinking water. Similar drains enter the river along it's length however unlike the Mannum drain, dilution factors are generally considered to reduce the risk of negative effects caused by short term upstream events from these sources. There was significant concern that either an accidental or ignorance induced event in the Mannum storm water catchment had significant potential to cause a problem for Adelaide's water supply. Specific work to detect and quantify hydrocarbons was included in this project for that reason.

Serious contamination events may seem to be an unusual or low risk situation however it is anything but. Warkworth water treatment plant was out of commission for 3 months at a cost in excess of $1M due to diesel from a local vehicle depot leaking into the river from which the town's drinking water is taken. Very few towns in NZ have secure drinking water sources and Auckland relies on both dilution and expensive treatment to prevent issues when drawing from the Waikato River.

Mannum is a town of just over 2000 people set on a slope above the current bank of the Murray River

**Image 12:** Mannum with respect to Adelaide

**Image 13:** Location on the River Murray

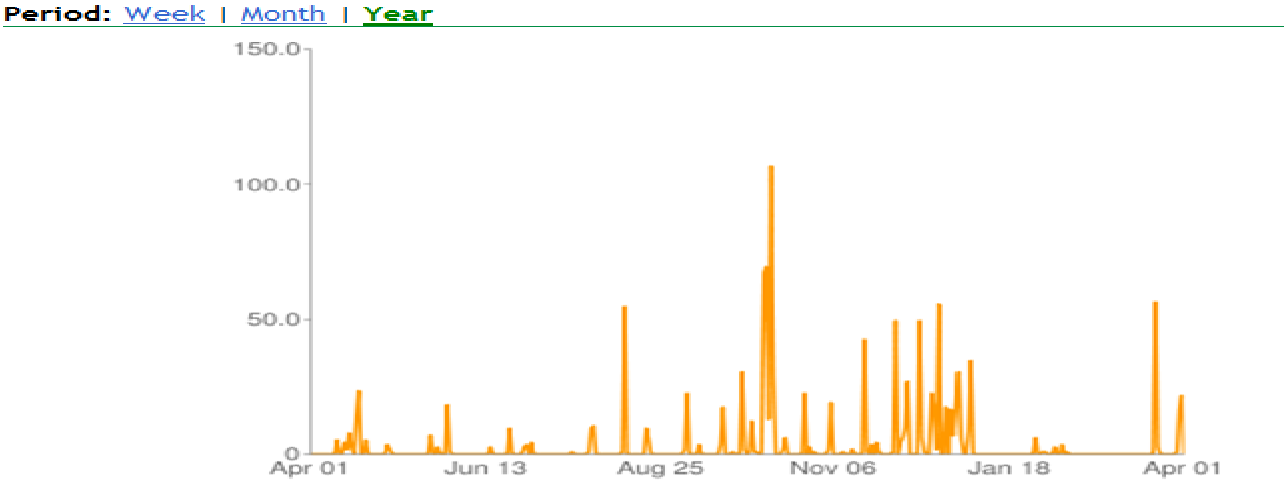

**Image 14:** Rainfall pattern - Rain in mm

Average rainfall in Mannum is around 350mm with months sometimes passing with no rainfall at all. The dry nature of the ground results in flash flooding when rain of any significance does arrive on the scene. A recent flood removed the entire concrete drain structure of the Mannum storm water system along with the monitoring pad and equipment in and on it. This required a partial rebuild of the gully the drain runs through and replacement of much of the measuring equipment.

**Image 15:** Destruction after Flood

The long periods of dry weather between significant rainfall events increases the likelihood of high levels of contaminants being washed into the storm water drainage system when rain finally arrives. Events such as an idiot changing his vehicle oil on a roadside or overspray of agricultural chemicals/pesticides by farmers bordering town into storm water catchments become more the longer between rainfall events. The savagery of rain events when they arrive increases the chances of localized flooding of storage sheds/commercial premises and subsequent release of the various compounds stored there into the storm water system.

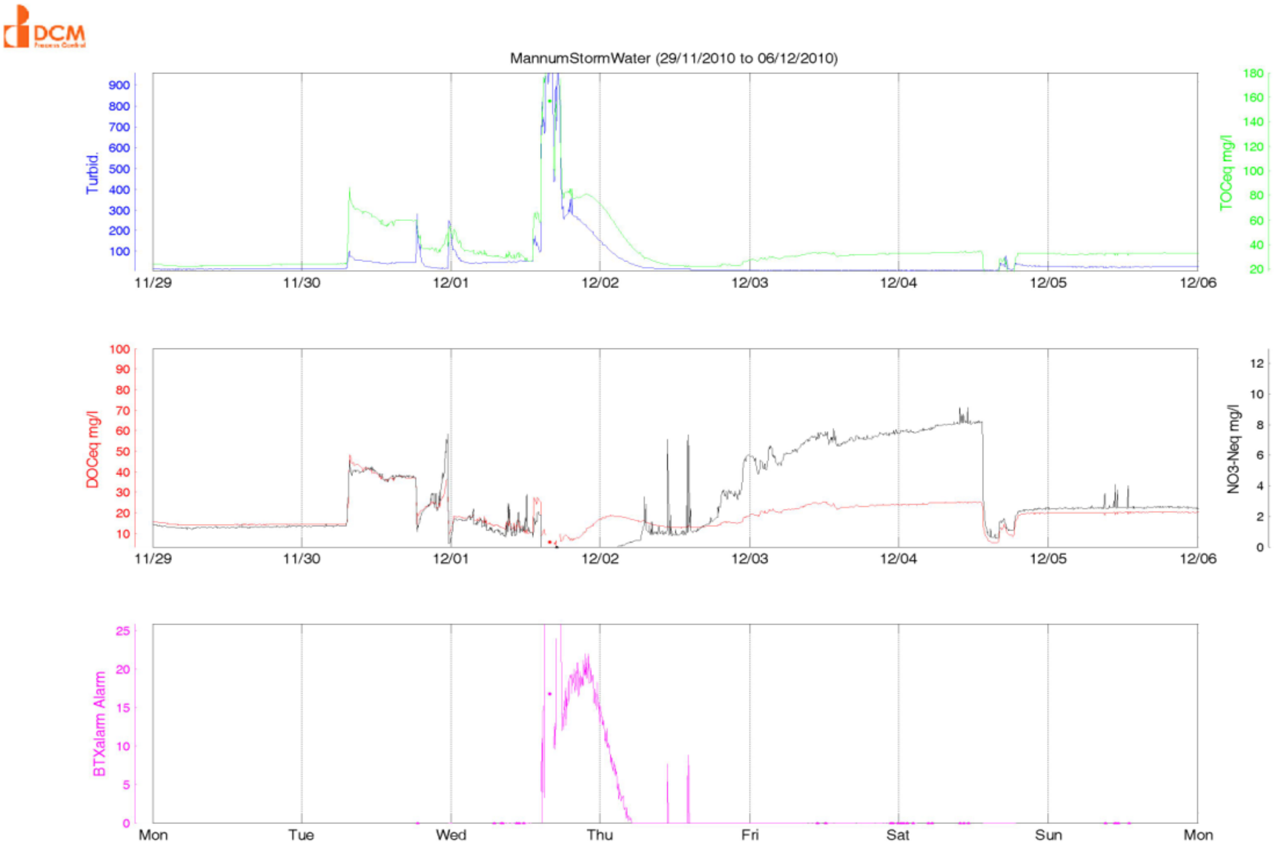

**Image 16:** Rain Event Mannum – "Cleaning"

One event of this type is shown in Image 16. Note that rain events ran over several days and involved short sharp showers in different areas of the catchment rather than general rain over the entire area.

Traditional thinking and management assumes a sudden high loading followed by a rapid drop off in contamination after which relatively clean water is expected. Here we can see that this is not the case. The initial rain event on the 30th Nov involved not much more than drizzle and saw a substantial rise in DOC with very little comparative shift in turbidity. Organic material rather than solids became dissolved and moved into the storm water system. Fortunately for the downstream water treatment plant intake, the volume was low and the dilution effect high.

The more intense rain on the 1st Dec was very different and involved a large amount of flow in a short time frame. This resulted in an overload of the sensing system in the DOC area during the peak of the event when turbidity was over 1000NTU. During this time it is clear that hydrocarbons were washed into the system as represented by the BTX parameter. This event was grab sampled by an auto sampler connected to the on line measurement system and activated by a BTX alarm.

The draining of the catchment after this event took a number of days with nitrate being the main contaminant until flows to the system from this source abruptly ceased on the 4th Dec. The reason for this is unknown and may relate to water levels in the source area of the catchment dropping to levels below a retention system.

BTX events occurred in approx 30% of the larger rain events in this catchment although sometimes they are very short lived as in Image 17 below .

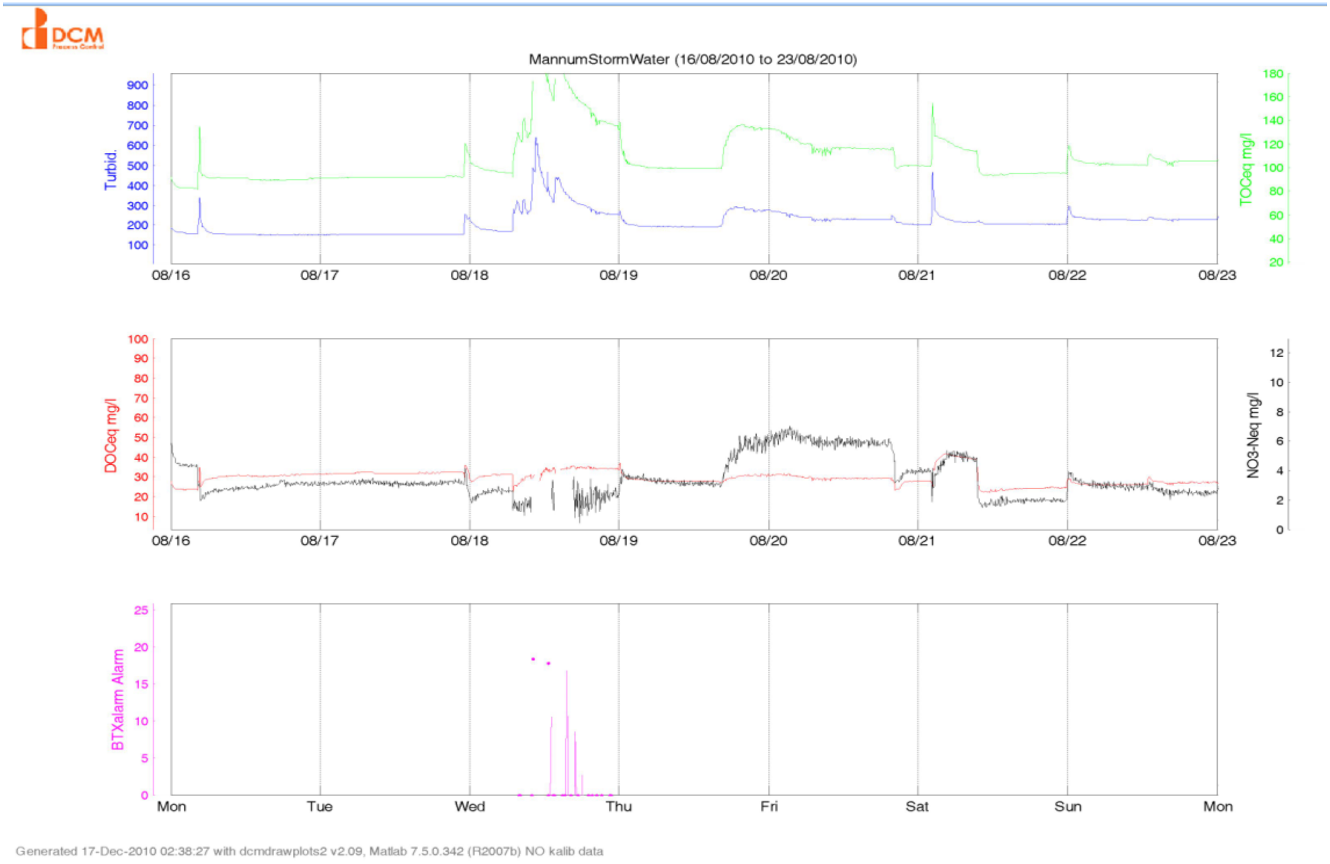

**Image 17:** BTX Event - Mannum

The presence of nitrate as a contaminant here is consistent and is something which would be worth tracking back to source of in some catchments. In this one, it is likely to prove to be a primary agricultural industry and political aspects are unlikely to weigh in favour of better management. BTX in the intake is a much higher short term risk and a BTX alarm in the storm water drain has operations watching the unit in the drinking water intake for any indication of contamination. In the year or so the system has been operational, this has not occurred however complacency with a water source supplying a large population is one thing that cannot be afforded.

## Conclusion:

So what does the data presented here show ?

1) Real time data shows that storm water events are often complex in their structure. They cannot be represented by simplistic first flush assumptions.

2) Highly organically contaminated water enter storm water systems and grab or composite sampling is unlikely to be effective at detection and prevention.

3) Regular monitoring of storm water drains in real time allows more effective evaluation of risk to downstream catchments

4) Regular monitoring in real time allows appropriate alarming of events and for grab sampler operation in sensitive catchments/applications.

5) The complex drivers for contaminant levels in storm water mean risk management of storm water requires on line data to be effective.

## ACKNOWLEDGEMENTS

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Urban stormwater contamination by polychlorinated biphenyls (PCBs) and its importance for urban water systems in Switzerland

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[b] Swiss Federal Institute of Technology, Laboratory of Environmental Chemistry and Ecotoxicology (CECOTOX), Lausanne, Switzerland

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