An Analysis of Sustainability and Efficiency of the Middle Route of the South-North Water Transfer Project in China

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Abstract Water shortage has been a long-time problem in Northern regions of China. Since 1952 the Chinese Government has been developing a solution to this problem. The solution is known as the South-North Water Transfer Project, and is divided into three routes: east, middle and west. This paper presents a study on the middle route of the project. Past studies have shown that the middle route will face several problems: leakage, soil instability, and pollution. The purpose of this paper is to examine the project's sustainability and efficiency by quantifying the impact of the three factors mentioned above. Hydrological data of the region were collected and used in calculations to produce the results. Leakage is quantified by a water budget model, which consists of an equation that accounts for different variables such as precipitation and evapo-transpiration. Soil instability is quantified by predicting the amount of unstable soil that will enter the canal as debris or mudslide in a given period of time. Pollution is quantified by looking at the scores of water quality in the source of transfer and comparing them to standards set by government agencies. The study showed that 1) only during extreme dry and regular dry years will leakage become a serious problem during transfer, 2) soil instability will not be a problem in roughly 10 to 20 years, and 3) pollution will be a serious problem due to poor water treatment in the source of transfer.

Introduction

Since 1952, the Chinese government began to plan a water transfer project to solve the widespread problem of water shortage in Northern China. The solution is known as the South-North Water Transfer Project (SNWTP) or *Nan Shui Bei Diao (NSBD)*. The project consists of three main routes: eastern route, middle route and western route (Figure 1). The projected annual transferred volume of water is 44.8 billion cubic meters by the year 2050. Of the three routes, the western route is still under planning and inspection; the eastern route is partly finished and in use. The middle route is the route that raises the most concern from water resources experts.

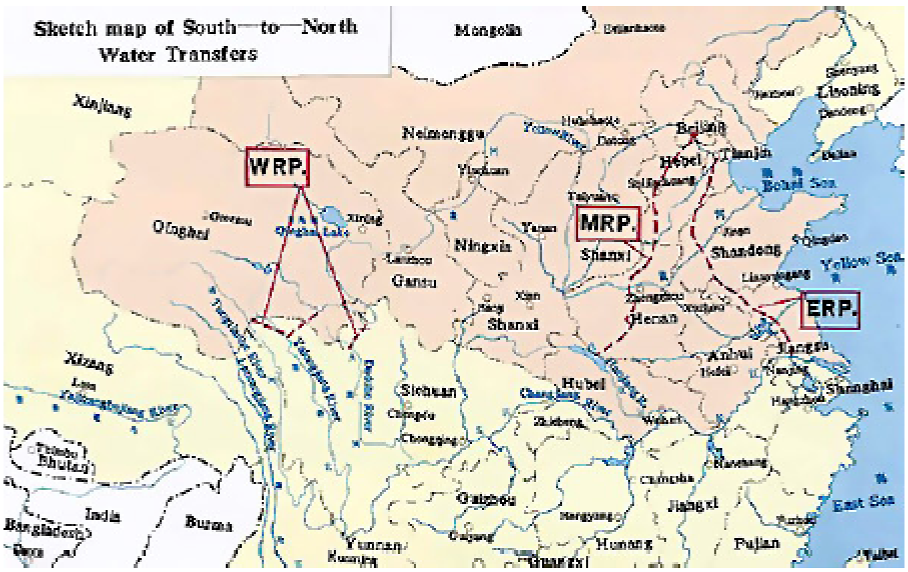

Figure 1. The South-North Water Transfer Project (source: Ministry of Water Resources (MWR))

The middle route project (MRP) starts from the Hanjiang River (a major tributary of Yangtze River) in Hubei Province in Central China (as shown in Figure 2). The main source of water for transferring would be extracted from the reservoir of Danjiangkou Dam. Upon the completion of the Three Gorges Dam, more water can be extracted for transfer. The destination of the middle route is Beijing, where water shortage has become a serious problem since the economic boom in the 1980s.

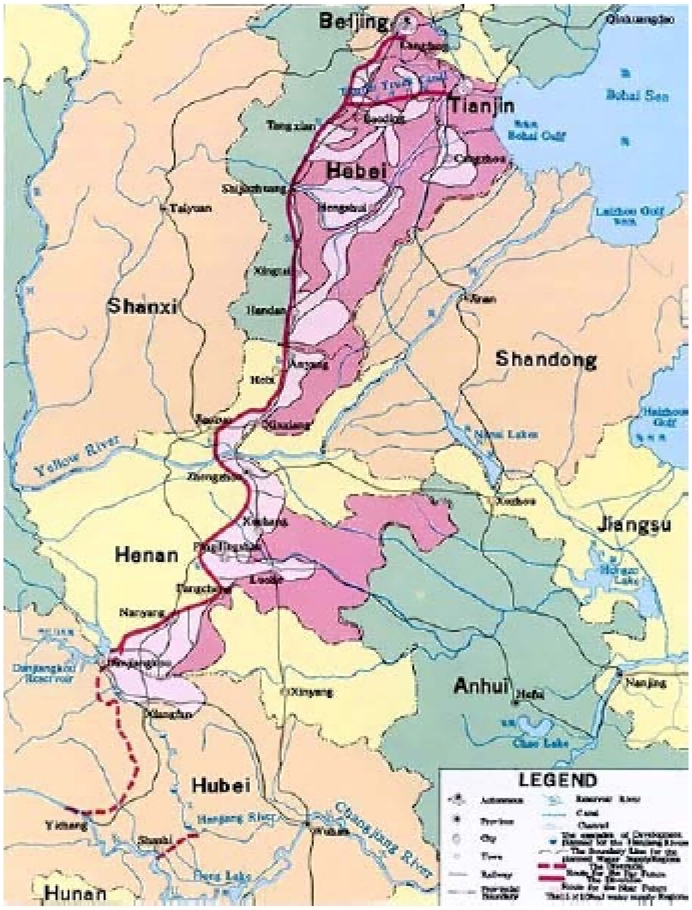

Figure 2. The Middle Route Project (source: MWR)

According to the official projections from the Ministry of Water Resources, the total annual transferred amount of the route is projected to be 11~19 billion cubic meters when the entire project is completed (i.e. even when a drought is present, the volume could still reach 11.0 billion cubic meters). This projection is based on the average annual precipitation of 500~700 mm, and a presumption of roughly no net change in the amount of water transferred (input ≈ output). In terms of water balance, the project would provide an equivalence of 70~120 mm of extra water input per year (Chen et al. 2004). This amount of water is adequate for supplying around 155 thousand square kilometers of land. However, due the limited supply, only residential and industrial usage in the cities of Beijing and Tianjin, and provinces of Hubei, Hunan and Hebei will have access to the transferred water. The canal will have a total distance of 1241.2 kilometers (NSBD 2004).

According to Wang and Ma (1999), the project will be affected by various geological and environmental problems, which are mainly caused by soil instability in the channel and/or on the river bank. In this paper, I will investigate three widely discussed potential problems of MRP:

Leakage Leakage is a serious problem because along the canal are about 700 kilometers underlain by highly permeable (permeability coefficient ~ 120 meters/day) soil layers (Wang and Ma 1999). Leakage not only will decrease the amount of water transferred, but also creates swamplands along the route. The bureau has created a newly designed material (other than concrete) whose permeability coefficient is around 10^-9 ~ 10^-7 centimeters/second. This material will be used through the middle route project. In this paper I will investigate how serious a problem leakage is by estimating how much water will be lost due to leakage.

Soil instability due to loess Loess is a special type of unsaturated soil. It can be often found in the Yellow River floodplain in Northern China. The MRP canal will enter the Yellow River watershed and uses the river as part of the transfer route. Loess is extremely unstable and easily collapses when wetted. Therefore loess becomes a potential problem in the MRP. Infiltration of water from the canal or precipitation may initiate the loess to enter the canal as debris or landslides. Loess in the canal creates sediment problems, water quality concerns, and may slow down or block the water flow. In this paper I will estimate how much loess would enter the canal and whether it would be serious enough to create sediment-related problem.

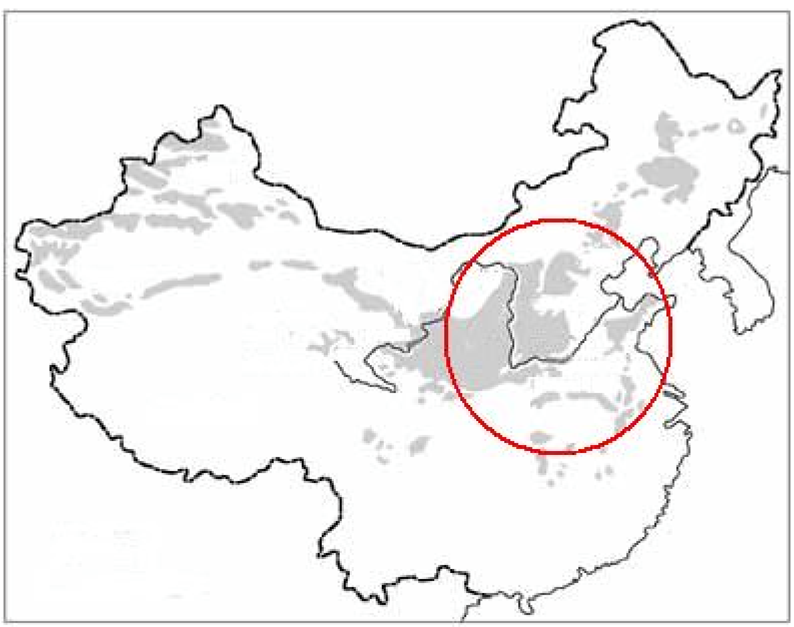

Figure 3. Loess coverage of Northern China

Pollution According to a recent report from Xinhuashe (the major Chinese newspaper and internet media), Hanjiang river has been suffering from point-source pollution such as direct dumping of untreated sewage. "More than 56 million metric tons of untreated sewage is dumped directly into Hanjiang and its tributaries. Pollution also comes from unreasonable usage of chemical fertilizer and pesticides," the report stated. Since Hanjiang is the major source of water in MRP, pollution problem in Hanjiang will affect the quality of water transferred. In this paper I will estimate the amount of pollution that the water will carry by using the standards provided by the Chinese government.

Methods

Data Data in the studied area will be collected. The studied area consists of two cities: Beijing and Tianjin, and three provinces: Hubei, Henan and Hebei. In which Hubei is where the water transfer originate, and the rest are the places that receive water. The main types of data are collected are weather station data, geographical data and water quality data. Weather station data include data such as precipitation, evapo-transpiration and pollution level. Geographical data include mainly loess coverage status in the watersheds of Yellow River and its tributaries. And Water quality data include those collected from numerous sites along Hanjiang River and its tributaries. Past hydrological studies in the area are also used as data. I have been working with Assistant Professor Xu Liang of the Civil Engineering Department and her PhD student Ben Runkle. They are able to provide most of the data such and weather station data in China. Therefore no on-site collection of data was needed.

Approach and Analysis My approach consisted of three parts: a water budget model mainly for calculating the effect of leakage, an equation predicting the amount of loess that will enter the canal and create sediment problem, and a model that estimating the effect of pollution.

1) Water budget model—I used the collected data and official projection figures to build a water budget model, which estimates the total amount of water that will be transferred. This model predicts the output (amount of water transferred) as a function of the input (from Hanjiang River) and several other variables such as precipitation and leakage. I then ran the model several times changing variables, and obtained projections of the total

amount of water transferred. Finally I could compare my result to the official projection and determine whether MRP has a major sustainability problem or not.

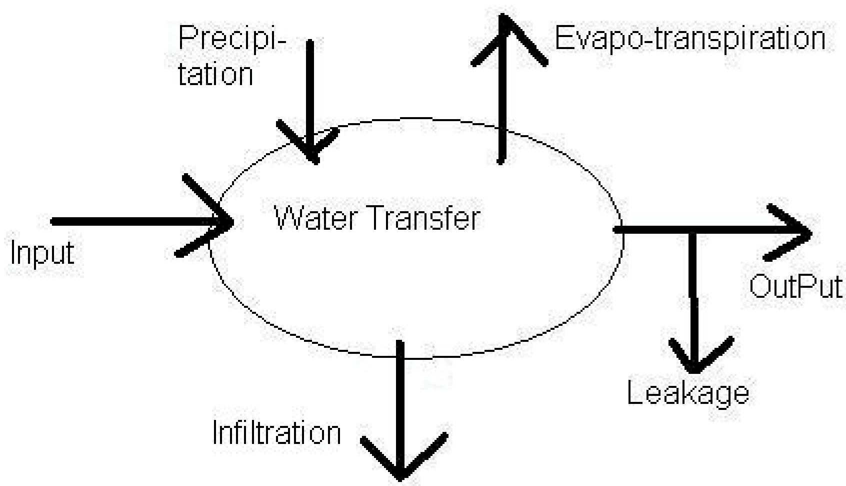

Figure 4. Water budget model

The formula is Output = Input + Precipitation (ppt) – Evapo-transpiration (ET) – Infiltration – Leakage **— equation 1**

2) Equation for loess problem—I estimated for the possible amount of loess that would enter the canal (depending on precipitation values) as debris or mudslide. I also found a threshold volume of loess in a canal that will create a sediment problem. Then I was able to conclude whether loess will be a serious problem in MRP or not.

Based on past studies (Ran et al. 2004) on loess in Northern China, the annual amount of loess enters the flow is a function of the area covered by loess in the watershed, the annual precipitation, and the total length of stream flow. And based on the weather station and geographical data (from Ran et al. 2004) on the tributaries of Yellow River including these parameters, the relationship can be generalized as follow:

$$C = (1.28\times10^{-4})A_{loess} + 0.00484\,ppt - 0.00358l$$ **— equation 2**

in which C is the total amount of loess load in the flow (in 100 million metric tons), A_{loess} is the area of loess coverage in the watershed (in square kilometers), *ppt* is annual precipitation (in mm) and l is the total length of stream flow (in kilometers).

3) Pollution—The Chinese government posts five levels (or scores) of water quality: I, II, III, IV and V, in which I is the best quality and V is the worst. The standard water quality is III, which is also the threshold level (i.e. pollutant concentration higher than the standards in III will be considered hazardous) (Huaihe River Commission (HRC), 2003). The criteria of each score are included in the appendix. I used this score system to track the possible quality of water by averaging the scores (I = 1, II = 2, etc.) from tributaries of Hanjiang River to get a sense of how polluted the water for transferring will be. This part will not require much calculation, but only data collection.

The comparison between my and the official predictions will be a scenario comparison, in which I will provide several different calculation results (generated by changing variables such as precipitation and evapo-transpiration) and compare them to the official prediction. Then I will be able to suggest under which scenario (some specific precipitation level, some specific evapo-transpiration level, etc.) the official predictions will most likely be met.

Results

Leakage Based on the data collected on the studied area and past studies (Chen 2004), the infiltration (precipitation enters soil) in the model is about 0% (negligible) during extreme dry years (annual precipitation ≈ 290 mm), 6.7% during regular dry years (annual precipitation ≈ 450 mm), 17.0% during normal (annual precipitation ≈ 600 mm) and rainfall excess years (annual precipitation ≈ 820 mm). Annual evapo-transpiration figures (portion of precipitation that will eventually evaporate or transpire) for each of the four types of years are roughly 280 mm for extreme dry years, 437 mm for regular dry years, 442 mm for normal years, and 425 mm for rainfall excess years. These figures are extracted from a range of data of a 30-year period (1971~2000). The highest and lowest annual precipitation and evapo-transpiration values are single year results (highest-1994, lowest-1999).

According to the official NSPD website, the part of the middle route in the area of my study will be constructed by a material with permeability coefficient of 10^-7 ~ 10^-9 cm/s. In other words, the annual loss to leakage can be controlled to a range of 0.315 mm ~ 31.5 mm. Since all the precipitation and evapo-transpiration data are in the range of hundreds of mm, only the worst scenario here (annual loss of 31.5 mm) would be significantly relevant. The calculations are based on the assumption that leakage is non-point (micro) leakage.

With projected input values of 70 mm ~ 120 mm per year, I picked three scenarios, 70 mm, 100 mm and 120 mm, to cross-analyze with different scenarios mentioned above. The following results are obtained by plugging the ppt, ET, etc. values into equation 1. Output (no leak) is the predicted output when not leakage is present. This is compared to the output when leakage is present (output (leak)) to conclude whether leakage affects the transfer.

Table 1. Extreme dry years (all units are annual figures, in mm)

Scenario #	Input	ppt	ET	loss to soil (0%)	output (no leak)	leakage	output (leak)
1	70	290	280	0	80	31.5	48.5
2	100	290	280	0	110	31.5	78.5
3	120	290	280	0	130	31.5	98.5

Table 2. Regular dry years

Scenario #	Input	ppt	ET	loss to soil (6.7%)	output (no leak)	leakage	output (leak)
4	70	450	437	30.15	52.85	31.5	21.35
5	100	450	437	30.15	82.85	31.5	51.35
6	120	450	437	30.15	102.85	31.5	81.35

Table 3. Normal years

Scenario #	Input	ppt	ET	loss to soil (17.0%)	output (no leak)	leakage	output (leak)
7	70	590	442	100.3	117.7	31.5	86.2
8	100	590	442	100.3	147.7	31.5	116.2
9	120	590	442	100.3	167.7	31.5	136.2

Table 4. Rainfall excess years

Scenario #	Input	ppt	ET	loss to soil (17.0%)	output (no leak)	leakage	output (leak)
10	70	820	425	139.4	325.6	31.5	294.1
11	100	820	425	139.4	355.6	31.5	324.1
12	120	820	425	139.4	375.6	31.5	344.1

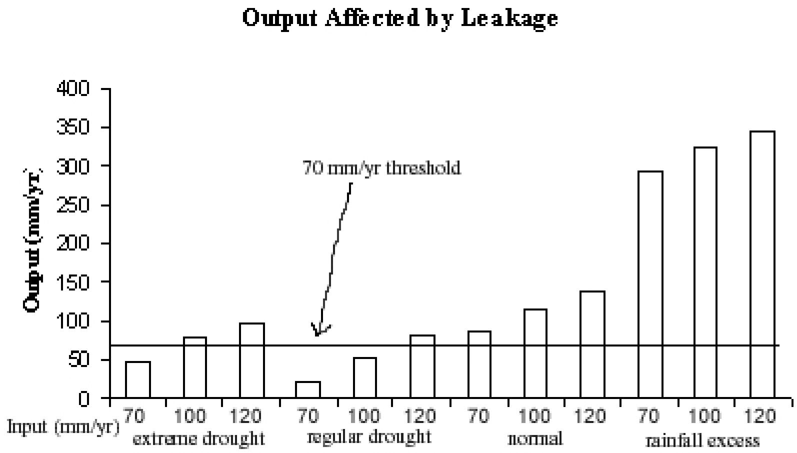

Figure 5. Summary chart of output values affected by leakage

Soil instability due to loess Based on past measurements, the average coverage of loess in the region is 42.4%. Therefore in the studied area, loess covers about 65720 square kilometers. Total length of stream flow in this case is 1241.2 kilometers. According to a report from the Yellow River Conservancy Commission (YRCC) in 2003, the minimum amount of load required for formation of sediment blockage is 13.75×10^7 metric tons (per year). I then plugged in these numbers with different amount of *ppt* (from the previous section) into equation 2:

Table 5

Scenario #'s	A_{loess}	*ppt* (mm/yr)	*l*	*C* (10^7 t/yr)	Threshold
1, 2, 3	65720 km^2	290	1241.2 km	5.37	13.75×10^7 t/yr
4, 5, 6		450		6.15	
7, 8, 9		600		6.87	
10, 11, 12		820		7.94	

Pollution According to the Hubei Province Environmental Report (Hubei Environmental Protection Bureau (HBEPB) 2002), the water quality of Hanjiang River at all the testing sites are all in the range of II's and III's, with an average score of 2.44. The quality of tributaries, except at two stations, is much worse than the main channel of Hanjiang River. The average quality score is 3.82. The starting point of MRP, Danjiangkou Reservoir, has a score of 4. The averages are regular un-weighted average.

In the main channel of Hanjiang River, the only category that did not match the criterion was total phosphorous. A total of five sites was discovered excess phosphorous, with each site had a score of III on total phosphorus (the standard is II). In the tributaries, a total of seven categories failed to match the criteria: kjeldahl nitrogen, permanganate index, soluble oxygen, biochemical oxygen demand (BOD5), oil category, total chromium (VI) and volatile phenol. Among these failed scores, an average score of 4.86 was posted (among total of seven sites, with the standards in the range of III and IV, varies by site). Finally, in Danjiangkou Reservoir, only nitrite level failed to match the criteria.

Discussion

Leakage According to the results, leakage becomes a serious problem during extreme dry years as well as regular dry years (tables 1 and 2). Scenarios 1, 4, and 5 failed to reach the projected amount of transfer. In fact, leakage is a bigger problem in regular dry years than in extreme dry years because high evapo-transpiration makes the soil very dry, therefore infiltration (which is measured by soil moisture content) is negligible. Although scenarios 2, 3 and 6 reach the projected amount (70 mm ~ 120 mm), the net change in water transferred in both scenarios are negative. In all other scenarios, leakage is not a serious problem because all the output values are within or exceed the projected amount of transfer.

According to Chen et al. (2004), seasonality is also a factor in determining water transfer, because in the region, most of the precipitation occurs in the months of July and August. This fact makes the water transfer a tougher task during extreme and regular dry years. One way to solve the problem is concentrate the water transfer in the first six months of a dry year (i.e. transfer the total maximum projected amount during January and June) to prevent further water shortage. This method has to be based on the assumption of that a drought is not present in Hanjiang River watershed. Base on the 50-year data, both Hanjiang River watershed and the studied area experienced drought in seven years in the 50-year span. The probability is 7/50 = 14%. However, according to historic records, this probability is much higher than the frequency of droughts in 2100-plus years (till 1949), in which span only 115 drought years was recorded (115/2100 = 5.5%) (Wei 1999). According to Wei (1999), this trend of increasing drought frequency is mainly due to increasing land abuse from over-development. In order to prevent water shortage within the MRP, the bureau might want to consider transferring water from Three Gorges Reservoir temporarily to solve the problem.

All of the above conclusions are based on the assumption that the material preventing leakage is working at a minimal level. Due to seasonal changes, the material might have a slightly different permeability coefficient (e.g. cracks might occur from freezing damage, thus leakage changes from non-point to point). And due to limited sources, seasonality corrections will have to be made in future research.

Soil instability due to loess Although loess loads in all scenarios are not serious enough to form sediment and blocked channel, the amount of load is each scenario is not negligible either. According to YRCC (2003), the annual sediment load of Yellow River is about 18×10^7 t/yr. In other words, the canal will carry about 29.8% in extreme dry years, 34.2% in regular dry years, 38.2% in normal years, and 44.1%in rainfall excess years, in equivalence of the total annual sediment load of Yellow River. If the bureau neglect the problem just because the annual sediment load is not serious enough to cause a problem, the problem might come back to haunt the region in tens of years because of accumulated sediments blocking the canal. The bureau should start to consider solutions regarding blockage. Although the amount of sediment load might be small comparing to the load in Yellow River, MRP does not have an exit to the sea like Yellow River does. Therefore sediment load might become a more serious problem in comparison with Yellow River.

Pollution According to the score standard posted by SNWTP, Hanjiang River does not meet the standard (III) despite the fact that its main stream has an average score below 3 (2.44). The main problem is that the tributaries of Hanjiang River are poorly treated, with a score close to 4 (3.82) and the failed categories combine for an average score of 4.86. By looking at the parameters that failed to meet the standards, one can conclude that most of the pollution comes from excessive fertilizer use (nitrogen, BOD) and industrial sewage (manganese, oil). Also, the water quality score for the starting point of transfer, Danjiangkou Reservoir, is 4, with a high concentration of nitrite. This does not include the illegal dumping of sewage that might occur along the canal. Since the canal is not finished, this prediction cannot be validated. But by looking at how people in the Hanjiang tributaries treat their water resource (i.e. literally using the rivers and streams as waste disposals), it is not difficult to conclude that the problem of pollution can only become worse in the future when the canal is completed. In addition to building waste treatment facilities along the canal, some basic environmental education must be provided to the residents in the region.

Since most of the official water quality reports in China are based on this I-V scoring system, it was difficult to track down the actual concentrations of pollution parameters such as dissolved oxygen and biodegradable organics. The above conclusion is only a general prediction of the possible level of water quality in the canal when the transfer project starts.

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Appendix: The Environmental Quality Standards for Surface Water (unit: mg/L)

No.	*Parameters/standards value/classification*	I.	II.	III.	IV.	V.
	Fundamental requirements	All the water bodies should not contain the following substances resulted by non-natural reasons: a. substances that can precipitate and become disgusting sediments; b. floating matter, such as fragment, floating slag, oil and other matter that leads to unpleasant perception; c. substances that produce disgusting color, smell and turbidity; d. substances that are harmful, toxic to or has negative physical effects on human beings, animals and plants; e. substances that benefits the disgusting aquatic organism.					
1	Water temperature	The water temperature variations caused by human activities should be controlled within: The maximum average weekly temperature rise in summer ≤ 1; The maximum average weekly temperature drop ≤ 2;					
2	PH	6.5~8.5					6~9
3	Sulfate*(by SO_4^{-2}) ≤	< 250	250	250	250	250
4	Chloride*(by Cl^-) ≤	< 250	250	250	250	250
5	Soluble Fe* ≤	< 0.3	0.3	0.5	0.5	1.0
6	Total Manganese* (Mn) ≤	< 0.1	0.1	0.1	0.5	1.0
7	Total Copper* ≤	< 0.1	1.0 (fishery 0.01)	1.0 (fishery 0.01)	1.0	1.0
8	Total Zine* ≤	0.05	1.0 (fishery0.1)	1.0(fishery 0.1)	2.0	2.0
9	Nitrate (by N) ≤	< 10	10	20	20	25

10	Nitrite (by N) ≤	0.06	0.1	0.15	1.0	1.0
11	Non-ionic Nitrogen ≤	0.02	0.02	0.02	0.2	0.2
12	Kjeldahl Nitrogen ≤	0.5	0.5	1	2	2
13	Total Phosphorus (by P) ≤	0.02	0.1(lakes,reservoirs 0.025)	0.1(lakes,reservoirs 0.05)	0.2	0.2
14	Permanganate Index ≤	2	4	6	8	10
15	Soluble Oxygen ≤	Percentage of saturation 90%	6	5	3	2
16	Chemical Oxygen Demand (COD_{Cr}) ≤	< 15	< 15	15	20	25
17	Biochemical Oxygen Demand (BOD5) ≤	< 3	3	4	6	10
No.	*Parameters/standards value/classification*	I.	II.	III.	IV.	V.
18	Fluoride (F^-) ≤	< 0.01	1.0	1.0	1.5	1.5
19	Selenium (four) ≤	< 0.01	0.01	0.01	0.02	0.02
20	Total Arsenic ≤	0.05	0.05	0.05	0.1	0.1
21	Total Mercury** ≤	0.00005	0.00005	0.0001	0.001	0.001
22	Total Cadmium*** ≤	0.001	0.005	0.005	0.005	0.01
23	Total Chromium(six) ≤	0.01	0.05	0.05	0.05	0.1
24	Total Lead** ≤	0.01	0.05	0.05	0.05	0.1
25	Total Cyanide ≤	0.005	0.05(fishery 0.005)	0.2(fishery 0.005)	0.2	0.2
26	Volatile Phenol** ≤	0.002	0.002	0.005	0.01	0.1
27	Oil Category ** ≤	0.05	0.05	0.05	0.5	1.0
28	Anionic Surface-active Agent ≤	< 0.2	0.2	0.2	0.3	0.3
29	Total Coliform Group Bacteria ***(/L) ≤	< 0.2	0.2	1000	0.3	0.3
30	Benzo(a)pyrene ***(ug/L) ≤	0.0025	0.0025	0.0025	0.3	0.3

Source: http://www.economics.utoronto.ca/brandt/Environment_Roumasset_et_al.pdf