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Research paper

Sediment Management Strategies for Hydropower Reservoirs in Active Agricultural Area

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Abstract

Ringlet, Jor and Mahang reservoirs are part of Cameron Highlands – Batang Padang Hydroelectric Scheme. Conversion of forest to agricultural and urban area within the catchment has caused Ringlet Reservoir to suffer severe sedimentation problem and waste dumping. This has caused operational difficulties to the hydropower operator. Based on estimation, sediment inflow into Ringlet Reservoir has increased multiple folds from 25,000 m^3/year in 1960s up to between 120,000 m^3/year to 200,000 m^3/year in 2010. This reduces the total storage capacity of Ringlet Reservoir to almost 50% of its original design value, and subsequently affects Jor and Mahang Reservoirs. Bertam Intake is often choked by the sediment built up within the area, thus limiting the running hours of the plant to generate electricity. Without sediment management strategies, the incoming sediment load into Ringlet Reservoir would increase tremendously and can cause the hydropower scheme to cease operation faster that its design life expectancy. Various mitigation strategies have been implemented such as dredging, construction of check dams and settling basins and flushing from the bottom outlet, resulting to an increase in storage. Despite these efforts which focus within the reservoir, the best solution is by control the sediment and waste at source, through the concept of an integrated catchment management. This requires concerted effort from the local authorities and public to ensure successful implementation. This paper outlines the methods, analyses and results of various mitigation strategies.

Keywords: *agriculture, catchment management, reservoir sedimentation, hydropower*

1. Introduction

Hydropower is the leading source of renewable and clean energy that generates 16.4% of the world's electricity [1]. It is the most flexible and consistent renewable energy sources that should be adopted as means to address global warming and other climate change issues. Tenaga Nasional Berhad (TNB) is the largest contributor to renewable energy in Peninsular Malaysia, with a total hydropower capacity of 2559.9MW [2]. The hydropower schemes are located in Kenyir (Terengganu), Perak and Cameron Highlands – Batang Padang (Pahang), comprises of 12 main dams and man-made reservoirs with additional functions for flood mitigation and water supply.

One of the biggest challenges of running hydropower is reservoir sedimentation. Researchers estimated that about 0.93% of the worlds' total storage capacity is lost annually due to sedimentation [3] [4]. World Commission on Dams estimated an average of 0.5% to 1%, and for individual reservoirs these values can be as high as 4–5 % [5]. Among operational problems related to reservoir sedimentation include intake chokage, loss of active and live storage for hydropower generation, loss of flood storage and possibility of extra pressure on dam structures. From the ecosystem perspective, reservoir sedimentation directly affects the water quality status of the lake and subsequently disturbing the ecosystem it supports. As reservoir sedimentation aggravates, the lifespan of the dam is adversely affected and could lead to discontinuation of dam operation. Operation and maintenance cost to run the hydropower scheme could increase dramatically due to sediment removal, as well as associated cost of repair due to abrasion and loss of power generation. These would adversely impact the financial viability of the hydropower schemes leading to total decommissioning. All problems related to sedimentation must be solved to ensure the reservoir remains in operation through its designed lifetime. Reservoir sediment management plan is very important and form part of the Operation and Manual (O&M) of any reservoir. This is also highlighted internationally through International Commission of Large Dams (ICOLD) Technical Committee on Sedimentation of Reservoirs.

Worldwide sediment management strategies for reservoirs focus on three major concepts of reservoir sediment management, namely control at watershed, diverting the sediment and sediment removal [6][7][8][9]. However, one extra concept named as adaptive strategies where sediment is not manipulated such as decommissioning, replacement, relocation of storage and raising of dam [8]. Switzerland adopted check dam, flushing, scouring pipe and gates, by passing, excavation and dredging to manage their reservoirs [6]. Japan adopted most mitigation measures such as by pass tunnel, slucing, flushing, modification of operation rule, check dam and dredging [7] [9]. Bypassing was used in Futatsano and Taki reservoirs while sluicing was used in Setoishi and Yambara reservoirs [10]. This includes sediment replenishment from the reservoir to the downstream channel. Operational changes, pressure flushing and water transfer were considered as sediment management strategies for Turtle Creek Lake and Perry Lake in US [11]. Strategies covering sediment bypass tunnel and drawdown flushing are capable to increase reservoir life between 2 to 21 times, while sabo dam construction is effective in extending the reservoir life by 2.4 times [12]. Modification of operating rule comprises of reservoir water level, sediment volume and rate of change of sediment volume were used as trigger for sediment flushing in Wankuai Reservoir, China [13]. Based on all the concepts mentioned, there is no one single solution to manage reservoir sedimentation but combination of several measures are needed to achieve optimum results [4].

Therefore, this study was initiated with aims to determine the most possible combination sediment mitigation measures suitable for Ringlet Reservoir. The novelty lies in reviewing all possible solutions on sediment management strategies as described by the previous researchers and combine the most feasible options it to derive the best mitigation plan that meet the site constraints.

2. Study Area

Cameron Highlands – Batang Padang Hydroelectric Scheme is located the state of Pahang and Perak bordered at Mukim Ringlet as shown in **Fig 1**. The scheme consists of Cameron Highlands and Batang Padang catchment, with total hydropower generation capacity of 262MW through 3 major power station namely Jor, Woh and Odak and 4 mini hydro power stations. Water is diverted from Cameron Highlands catchment comprises of Plau'ur, Telom, Kial, Kodol, Bertam and Ringlet, and impounded in 0.5km^2 of Ringlet Reservoir at Sultan Abu Bakar Dam (SAB Dam), Ringlet. The dam is equipped with three (3) radial gates and 1 tilting gate to release excessive flood water to the downstream Sg Bertam that flows across Bertam Valley [14].

Jor Power station utilises water from Ringlet Reservoir through Bertam Power Intake, and discharge back to Jor Reservoir in Batang Padang district. Water from tailrace of Jor Power Station, Sg Batang Padang and other tributaries flow into Jor Reservoir. Water from Jor Reservoir is channelled to Woh Power Station through Menglang Intake. Tailrace of Woh Power Station discharged back to Mahang Reservoir and eventually into Sg Batang Padang, as illustrated in **Fig 2** below. The scheme was constructed in late 1960s by the Central Electricity Board and after privatisation exercise in 1990, Tenaga Nasional Berhad (TNB) has been operating and maintaining the scheme.

Cameron Highlands catchment has an average elevation of 1180m with steep topography. 26% of the terrain is steeper than 25º and 60% of the land is steeper than 20º [15]. The area has undergone excessive land clearing and deforestation since 1970s, translated into active agricultural, commercial area and urbanisation. As of 2010, only 65% of the catchment is forested and 24% is agriculture, 5% is tea plantation and 5% is urban area with mixed residential and commercial areas. The area is famous tourist attraction due to its cool weather and beautiful landscapes. Batang Padang is less disturbed with predominantly forest cover at much flatter topography. Average annual rainfall for Cameron Highlands and Batang Padang is 2,800 mm and 2,085 to 3,527mm mm respectively.

The whole scheme is unique as it utilises water from different states across several districts. Details of the contributing catchment is summarised in **Table 1** below.

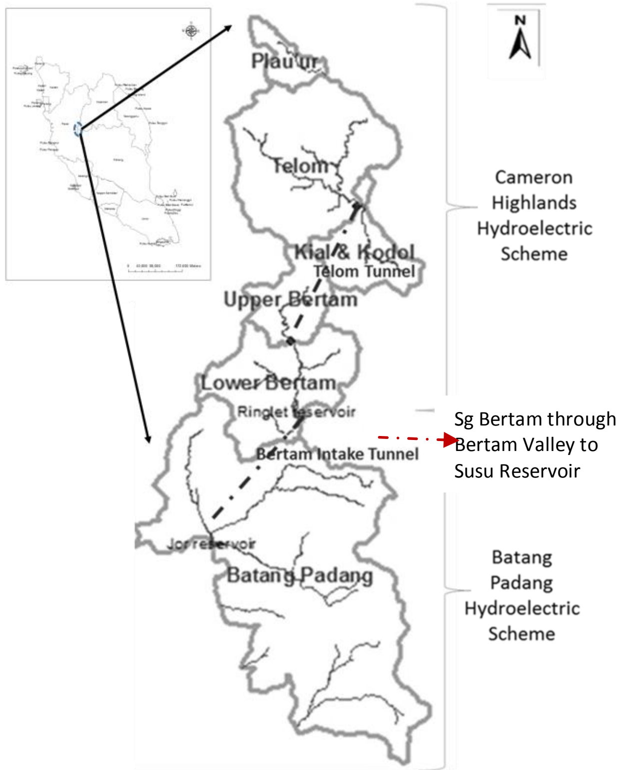

Fig 1: Location of Cameron Highlands –Batang Padang Hydroelectric Scheme

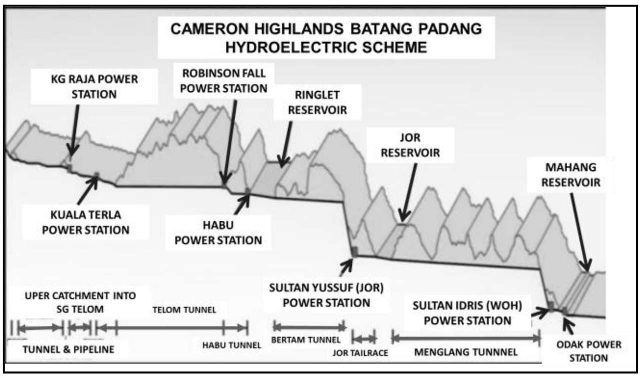

Fig 2: Longitudinal profile of Cameron Highlands – Batang Padang Hydroelectric Scheme (modified) [22]

Table 1: Catchment area for Cameron Highlands – Batang Padang Hydroelectric Scheme

Catchment	Sub-catchment	Area (km^2)	Cumulative Area (km^2)
Bertam	Upper Bertam	21	
	Lower Bertam	50	71
Telom	Telom	78	
	Kial & Kodol	22	
	Plau'ur	9.8	110
Jor	Keteh	6	
	Jor	30	
	Batang Padang	46.5	
	Sekam	42.5	
	Lengkok	11	
	Bot	10	
	Chenes	2	
	Tidong	6	
	Woh	55	209
Mahang	Mahang Reservoir	0.68	334.68

Sg Bertam downstream of SAB dam eventually flows into Susu Reservoir, located at about 21km from Bertam Valley along Jalan Ringlet – Kuala Lipis. Susu Reservoir is part of Ulu Jelai Hydroelectric Scheme which was impounded in 2016. To summarise, the whole Cameron Highlands – Batang Padang and Ulu Jelai Hydroelectric Scheme compose of cascading dams, reservoirs and hydropower station utilising source of water from Cameron Highlands Catchment. Therefore, any land degradation in Cameron Highlands poses threat to water source and would transfer similar problem to the downstream reservoirs.

3. Operational Challenges

Overdevelopment in Cameron Highlands catchment since 1960s has resulted in deforestation, increase of urbanisation and agricultural activities especially for flower and vegetable farming. **Fig 3** illustrates the land use evolution in the catchment. The use of plastic roofs for agricultural worsen the situation, by increasing the surface imperviousness leading to higher runoff rate. Previous studies [15][16][17] have shown that the operation and energy generation of the hydro stations of the Cameron Highlands Scheme are affected by the land development. High erosion rate in the catchment is translated into high sedimentation rate in the reservoir especially Ringlet. The rate is dynamic and highly dependent of land use activities. Studies using data set between 1990 to early 2000 indicated critical soil loss and sedimentation rate in Cameron Highlands, ranging from 150,000 m^3/year up to 530,000 m^3/year [18]. Agriculture activities inclusive of market gardening, floriculture, mixed agriculture, tea and orchard significantly contributed the highest rate of soil loss in Cameron Highlands [19]. However, using revised data set between 2000 to 2010 for sediment yield modelling and sampling exercise, sedimentation rate is in the range of 120,000 to 200,000 m^3/year of sedimentation rate [19]. Despite the variation in the estimation, sedimentation rate in Cameron Highlands is considerably excessive compared to other areas in Malaysia.

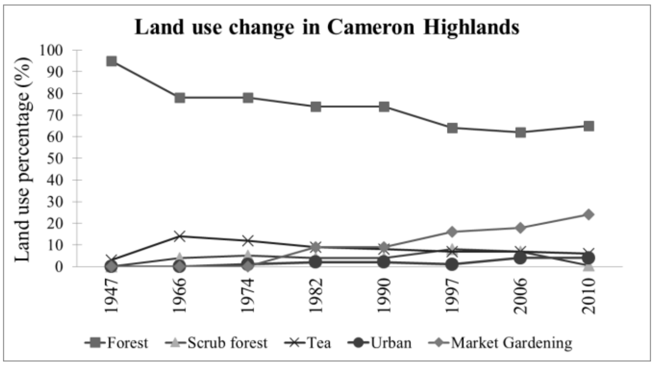

Fig 3: Land use evolution indicating growth of agricultural areas

Bathymetry survey conducted on Ringlet Reservoir indicated that the total storage capacity of Ringlet Reservoir decreased from 6.7 million m^3 in 1965 to 6.2 million m^3 in 1984 and to 4.4 million m^3 in 1999 [20] and as of 2008, Ringlet has lost 56% of its storage. As the reservoir live storage is lost to sedimentation, generation capacity is adversely affected causing loss of revenue to the power station. At this rate, Ringlet would be completely silted faster that its designed life of 80years. Not only that, flood storage is also affected causing the reservoir to lose its function for flood control. Whenever flood waters come, this excess of water has to be released to the downstream area via automatic gates, with potential risk of flooding. This was translated into reality in Lembah Bertam Flood during October 2013, as illustrated in **Fig 4.**

As Jor Reservoir utilizes water diverted from Ringlet for power generation, similar sedimentation problem is expected to occur. Bathymetry survey in 2014 indicated 45% of Jor storage is also lost to sedimentation, and potentially affecting power generation at Batang Padang Hydroelectric Scheme. Similarly, Susu Reservoir is also utilizing water diverted from Telom and Bertam which are also subjected to high sediment load due to active agricultural activities in these catchment. With these aggravated problems, running a hydropower plant in Cameron Highlands – Batang Padang is becoming more challenging. Excessive development leads to high sediment load and subsequently high cost of sediment removal would affect its financial performance.

Fig. 4: Mud flood in Cameron Highlands [21]

In order to ensure hydropower generation continues to operate, TNB has invested mostly in dredging and sediment removal from the intakes and the reservoir itself. Sediment disposal area has become limited in the area. Unfortunately, without proper control on development at the hillside slopes and excessive deforestation, dredging is not a sustainable solution.

4. Sediment Management Strategies – Method and Efficiency Assessment

Prior to planning of management strategies, extensive data collection is needed encompasses of rainfall, flow and sediment monitoring, reservoir bathymetry surveys and soil investigation at the study area. Using these data, sediment inflow rate is estimated based on sediment rating curves, comparison between two successive surveys as well as hydrological modelling, hydraulic modelling and sediment transport to determine spatial and temporal distribution of sediment load. **Fig 5** summarises the methodology used to derive the sediment management strategies for Ringlet Reservoir. The following strategies were adopted for Cameron Highlands:

1. Control at source
2. Sediment removal

4.1. Sediment Removal via Dredging

Within the capacity of TNB, sediment in Ringlet Reservoir is continuously removed via dredging, of which the dredged material is dried temporarily at the designated decantation area before being transported and disposed at Sg Jasik Disposal Area. TNB has spent a total of RM180 million since 2001 to remove sediment and it has increased to RM40million in 2014 with the removal target of 750,000 m^3/year to restore storage lost from Ringlet Reservoir [21]. In addition, TNB has to remove waste that often dumped into the river network and eventually accumulated in the reservoir itself. However, dredging alone is not a sustainable solution, due to potentially larger sediment loads entering the reservoir as compared to capacity of removal. Land availability for disposal area is becoming limited in the future which can subsequently increase the total cost of removal. Therefore, TNB has concurrently looking into other solutions such as trapping the sediment further upstream before it enter the lake. **Fig 6** illustrates typical dredging activities within Ringlet Reservoir.

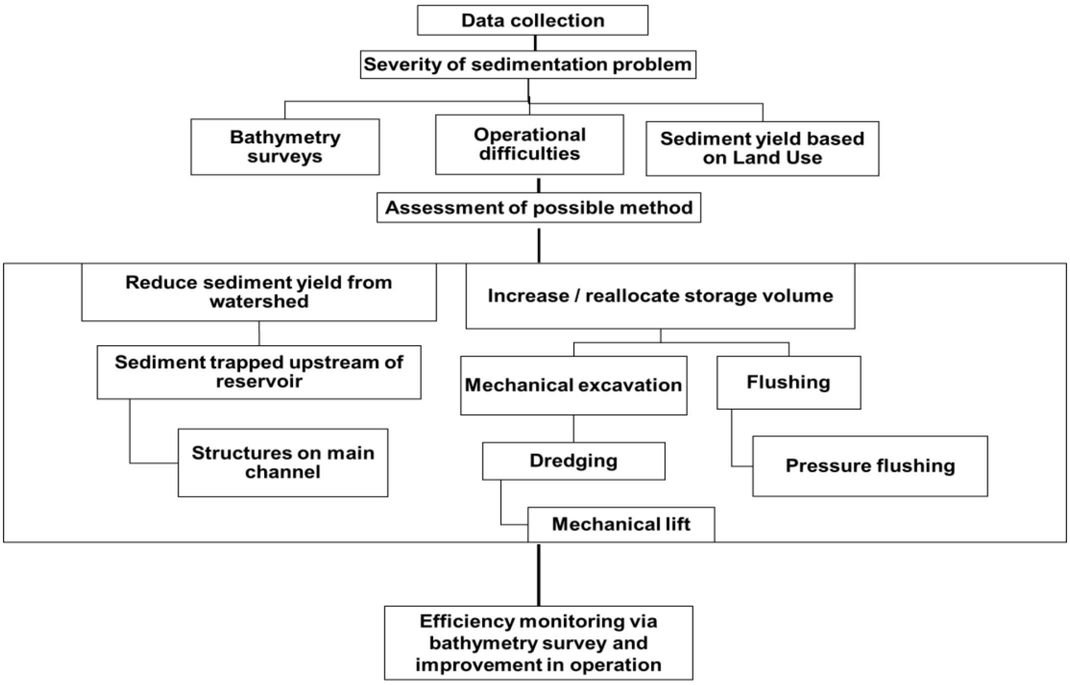

Fig 5: Summary of methodology to derive sediment management strategies for Ringlet Reservoir

Fig 6: Dredger Pump with Installed Pipeline at Ringlet Reservoir

4.2. Check Dam and Settling Basin

Check dam is a vertical barrier, with lower crest height in the middle and constructed across waterways or rivers to control the flow velocity such that sediment particles are trapped in the settling basin upstream the check dam structure. The rate of sediment trapping efficiency depends of the area and settling velocity of the sediment particles. As one of the method to reduce sediment inflow into Ringlet Reservoir, check dams and settling basin were proposed in 2010 to be constructed at the main rivers flowing into Ringlet, namely Sg Ringlet and Sg Bertam. Detail engineering design encompasses of survey, soil investigation, rainfall runoff and sediment transport using MIKE 11 and MIKE 21 was undertaken to derive the best sizing of the basin, equipped with 2m height of check dam, with potential to trap up to 150,000 m^3/year of sediment from the total estimated annual inflow of 310,000 m^3/year. The main objective was to save cost on sediment removal as it is cheaper and easier to dredge at the upstream part of the reservoir instead of from inside of the reservoir. **Fig 7** depicts the layout of check dam structures at Habu End.

4.3. Reservoir Flushing

Sediment flushing is a method used to remove existing sediment from the reservoir through scouring, re-suspending of the sediment and forcing the re-suspended sediment to flow out of the reservoir. This is done by allowing an opening at a low-level gate/tunnel on the dam to allow sediment to flow through. Flushing is suitable for reservoir channel having a steep slope and high river discharge allowing for effective transport of sediment downstream.

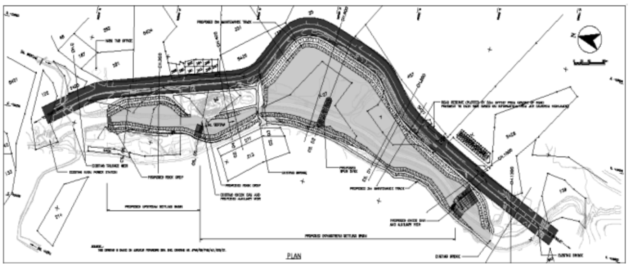

Fig 7: Design layout check dam and settling basin [22]

SAB dam is equipped with bottom outlet structure of 1.88m diameter steel penstock through the dam buttress section with trash rack, a butterfly valve and hollow jet valve to discharge flow to the downstream area as part of maintenance procedure of the dam. This bottom outlet has been used occasionally at low discharge capacity as part of function testing and local removal of sediment near the dam structure. However, this is limited by the outlet discharge capacity hence detail study should be conducted to evaluate the feasibility of bottom outlet to flush sediment. **Fig 8** below illustrates sediment flushing at SAB dam through the bottom outlet.

Fig 8: Sediment flushing through bottom outlet at SAB dam

4.3. Integrated Catchment Management and Community based Program

As part of the efforts to control sediment and solid waste, TNB is collaborating with government agencies to embark on catchment management and community-based disaster management program to educate, promote and inculcate awareness on sediment control and dam safety to the local community and stakeholders in Cameron Highlands. Government Agencies who are involved such as Land Office, District Office, Department of Irrigation and Drainage, Department of Environment, Civil Defence Department, local farmers, schools and local villagers including Orang Asli. Among the key issues highlighted and discussed during workshops include erosion and sediment control, sustainable farming, disaster management and improvement of infrastructures. Erosion and sediment control guideline produced by Department of Irrigation and Drainage in 2010 should be used to control soil erosion and sediment production at the area, especially at the agricultural plot. Similarly, river buffer zone is to be reinstated based on the relevant gazettment document, to limit the flow of pollutants and eroded soil into the river network. Sustainable agricultural activities with controlled urbanisation and efficient disaster management has become the concept for future development in Cameron Highlands in reference to local structural plan. Farmers were given awareness and technical know-how on methods to control erosion at their respective plots by promoting installation of localised sediment trap, vegetation cover and terracing.

As flood is related to loss of storage due to sedimentation, public engagement and education program become an important aspect of the management strategies. To manage public perception and promoting awareness on flood safety, close engagement through workshops and seminars with public and local community were introduced, including table top and drilling exercise to improve flood safety awareness in the community of Bertam Valley that is located immediately downstream of Ringlet Reservoir. Community was taught on what to do during releases from the dam in the event of heavy rainfall.

It is important to note that this long term effort requires high level of commitment from all parties, with common goal to reduce pollution and to promote sustainable development of Cameron Highlands.

4.3. Assessment of Sediment Removal Efficiency

In order to assess the results and efficiency of the mitigation measures undertaken, bathymetry survey, operational regime and sediment monitoring were conducted. Bathymetry survey in 2016 conducted in 2016 indicated storage recovery of 18% (500,000 m^3) compared to survey in 2008. This improvement is due to intensive efforts on dredging and periodic flushing. However, reduction of sediment production within the watershed could not be gauged effectively, since the integrated catchment management is still at the planning stage. **Table 2** summarises the sediment mitigation efforts and their effectiveness based on the survey record.

Table 2: Sediment mitigation efforts and their effectiveness

Management strategies undertaken between 2008 - 2018	Location	Effectiveness indicator
Dredging	Ringlet Reservoir including Sg Bertam and Sg Ringlet check dam area	1. Ringlet Reservoir has improved storage by almost 18% from 2008 to 2016 2. Full opening of Bertam intake
Check dam	Sg Bertam and Sg Ringlet	
Periodic flushing	SAB dam	

5. Conclusion

Hydropower operation in rapidly changing land use especially in agricultural area is challenging. Ringlet Reservoirs is surrounded by agricultural activities and commercial areas. This has led to increase in sediment inflow into the reservoir, causing loss of storage, intake chokage and other operational problems. Sediment mitigation measures specifically for this reservoir have been developed and implemented based on the site conditions, comprise of dredging, check dam and periodic flushing. Intensive efforts undertaken since 2008 have proven effective in recovering the lost storage and improving the operation of the power plant. However, the dynamic change of land use especially uncontrolled increase in agricultural and urbanization would lead to more sediment load. This would affect the efforts undertaken this far. That is why the best solution is through an integrated catchment management. TNB has embarked on strategic collaboration with respective government agencies to control sediment at sources through integrated catchment management. This will serve as holistic approach to preserve water resources, pollution control, and disaster management and eventually towards sustainable development of the area for the benefit of all parties. The same concept would be applied to other reservoirs as well.

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