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鮭魚產卵礫石河床最佳沖淤水流之研究

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Optimal flushing flows for salmonid spawing gravels

中文摘要

本研究利用礫砂河床沖淤數值模式探討非劣勢沖淤方案與其協商值。模擬結果顯示沖淤效率隨流量而增大，但流量超過100m^3/s後流量之敏感度降低，沖淤系統可簡化為雙目標系統。礫石損失量與沖淤水體積為互斥結果。當河床泥砂條件較差時，可行方案較為受限並且花費較高。本研究將互斥結果之協商值以目標空間可行解方式量化呈現。

關鍵詞：模式模擬，沖淤水流，多目標系統，協商值，非劣勢方案。

ABSTRACT

A simulation approach to evaluating flushing flows and exploring the tradeoffs associated with noninferior flushing options is presented. A two-fraction sediment routing model is used to simulate the gravel-sand bed response to flushing flows. A series of numerical simulations are carried out with a range of flows and pre-flushing bed sediment conditions. The results reveal that the flushing efficiency is higher for the larger flow. However, for flows greater than ~100 m^3/s the flushing duration is less sensitive to the flow discharge, thus the system may be simplified as a bi-objective one. The gravel loss and water volume are two conflicting outcomes within the noninferior flow region. Under a worse bed sediment condition, the feasible flushing options are constrained in a narrower range and also associated with higher costs. The tradeoffs between the conflicting outcomes are quantitatively displayed with the transformed feasible solutions in the objective space.

Keywords: Model simulation; flushing flow; multiobjective system; tradeoff; noninferior option.

1. Introduction

Flushing flow releases have been increasingly proposed as an effective alternative in dam management and a required component of riverine restoration programs. Releases of sediment-maintenance flushing flows are important for mitigating the adverse effects caused by the intrusion of fine sediment into gravel beds, in particular the degraded quality of salmonid spawning gravels (Wu, 2000). However, reservoir releases are generally associated with financial and environmental costs, such as the lost power generation, reduced water supply, and loss of spawning gravels to the downstream. Figure 1 depicts the interrelations between the components involved in a flushing flow and sediment transport (flow-transport) system. It shows that the duration of a flushing flow (labeled as Objective 1) is directly governed by the flushing goal (i.e., the quantity of sand to be removed) and the sand transport rate. Of these two governing factors, the former corresponds to the bed sand content (a transient state variable, connected by a dashed line) and the desired bed quality (or the maximum acceptable sand content); the latter is a complex function of flow discharge (labeled as a decision variable), implying that the flushing duration indirectly relies on the magnitude of flushing flow. Suppose that the duration for achieving the flushing goal can be determined, the released water volume (labeled as Objective 2) is simply evaluated by the product of flow discharge and duration. Similarly, to estimate the gravel loss (labeled as Objective 3), one needs to calculate the difference between the total gravel output and input through a stream reach, which involves the integration of gravel transport rate over the flushing duration. A recently developed two-fraction sediment routing model (Wu and Chou, 2003) is applied to the conditions of a representative gravel-bed river for exploring the tradeoffs associated with flushing flows. A series of numerical simulations are then carried out with a range of flows and bed sediment conditions. The simulation results are used as a basis for determining the noninferior options, which are further transformed to the feasible options in the objective space for demonstration of the tradeoffs between the conflicting outcomes.

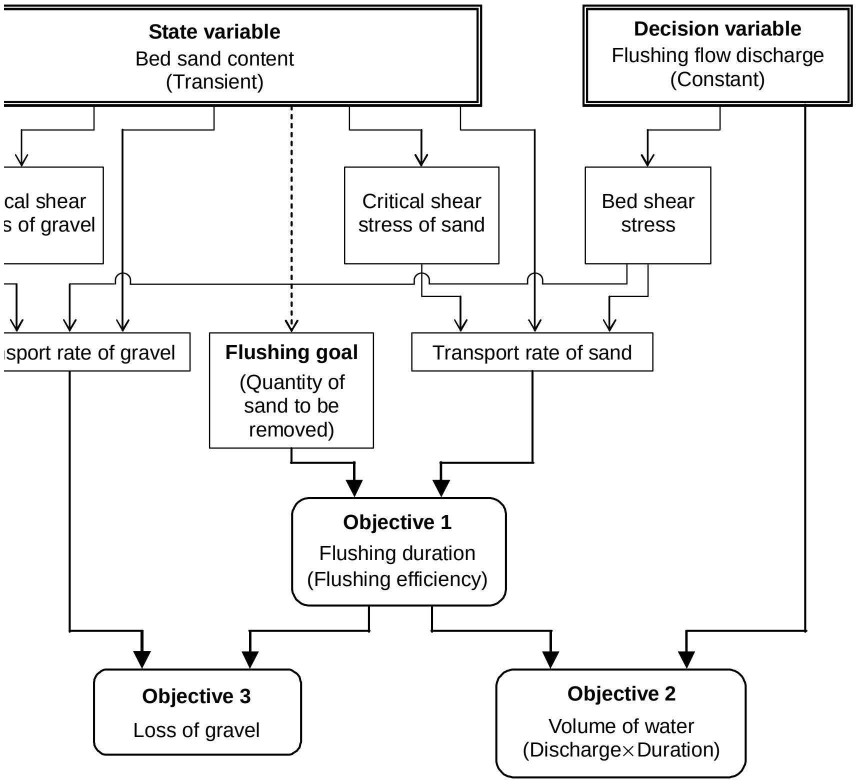

Figure 1. Interrelations between the components and outcomes involved in a flushing flow and sediment transport (flow-transport) system

2. Evaluation of Flushing Options

For the flow-transport system depicted in Figure 1, the outcomes (Objectives 1-3) are substantially influenced by the bed-sediment condition (a state variable), ultimate goal to be achieved (flushing goal), and flushing flow discharge (a decision variable). To systematically evaluate the flushing options under the given bed-sediment condition, a series of numerical simulations are carried out with a range of flows (85 to 200 m^3/s). This flow range is based on the observations that little transport of bed material occurred for $Q \leq 85\,m^3/s$ at the Trinity River study site (Wilcock *et al.*, 1996). Five different values of pre-flushing f_s, ranging from 0.24 to 0.32 (typical values for the gravel-bed rivers in need of flushing), are used in the simulations. The flushing goal is specified to remove sand from the channel bed such that $f_s \leq 0.05$ is met in the entire simulation reach.

2.1 Flushing Duration vs. Flow Discharge

Variations of flushing duration with flow under various pre-flushing f_s values (Figure 2) reveal that the required flow duration to achieve the specified flushing goal decreases with the increase of flow discharge, i.e., the larger flow is more efficient in sand cleansing. For a given flow, it is shown that the flushing duration is longer under the higher pre-flushing f_s value. Although the flushing efficiency is higher for the greater flow, the marginal efficiency associated with the greater flow is considerably lower. The marginal flushing efficiency for the range 100-200 m^3/s is 93% lower than that for the range 85-100 m^3/s. For flows greater than ~100 m^3/s, increasing the flow magnitude does not significantly increase the flushing efficiency. As such, for these greater flows, it is very unlikely that the flushing duration would be a major concern in the evaluation of flushing options. Assessment of these larger flows, thus, needs to examine other outcomes of the system.

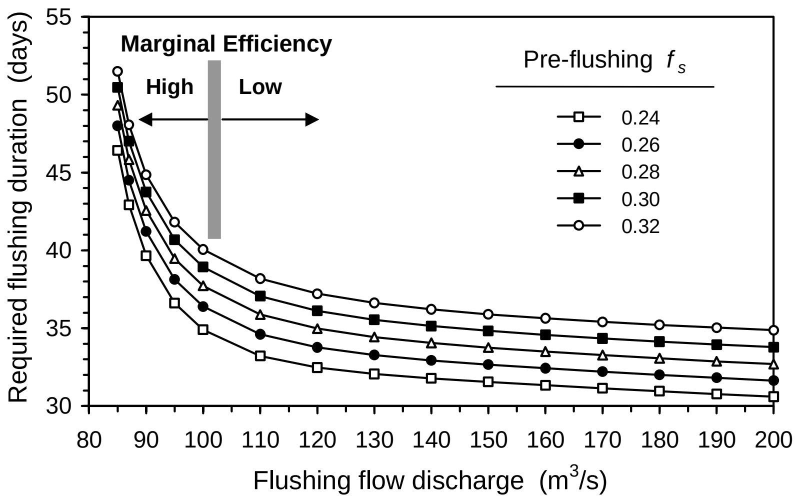

Figure 2. Variations of flushing duration with flushing flow discharge under different pre-flushing f_s values

2.2 Released Water Volume vs. Flow Discharge

Variations of the released water volume as a function of flushing flow under five different pre-flushing f_s values (Figure 3) reveal that for $Q <$ ~95 m^3/s the released water volume decreases with the increase in flow discharge. However, for $Q >$ ~100 m^3/s, the released water volume increases with flow discharge. For $Q < \sim 95$ m^3/s the decline in flushing duration is faster than the increase in flow discharge, whereas for $Q > \sim 100$ m^3/s the decline in flushing duration is not as fast as the increase in discharge. The joint effect of this increasing flow discharge and decreasing duration for $Q > \sim 100$ m^3/s is the monotonically increasing water volume, implying that a larger flow is associated with a greater flushing efficiency but also a greater amount of water consumption. As pointed out previously, for $Q > \sim 100$ m^3/s the flushing duration is less sensitive to the flow discharge. In view of the greater water consumption associated with the larger flows (i.e., for $Q > \sim 100$ m^3/s), a smaller flushing discharge might be preferred to minimize gravel loss.

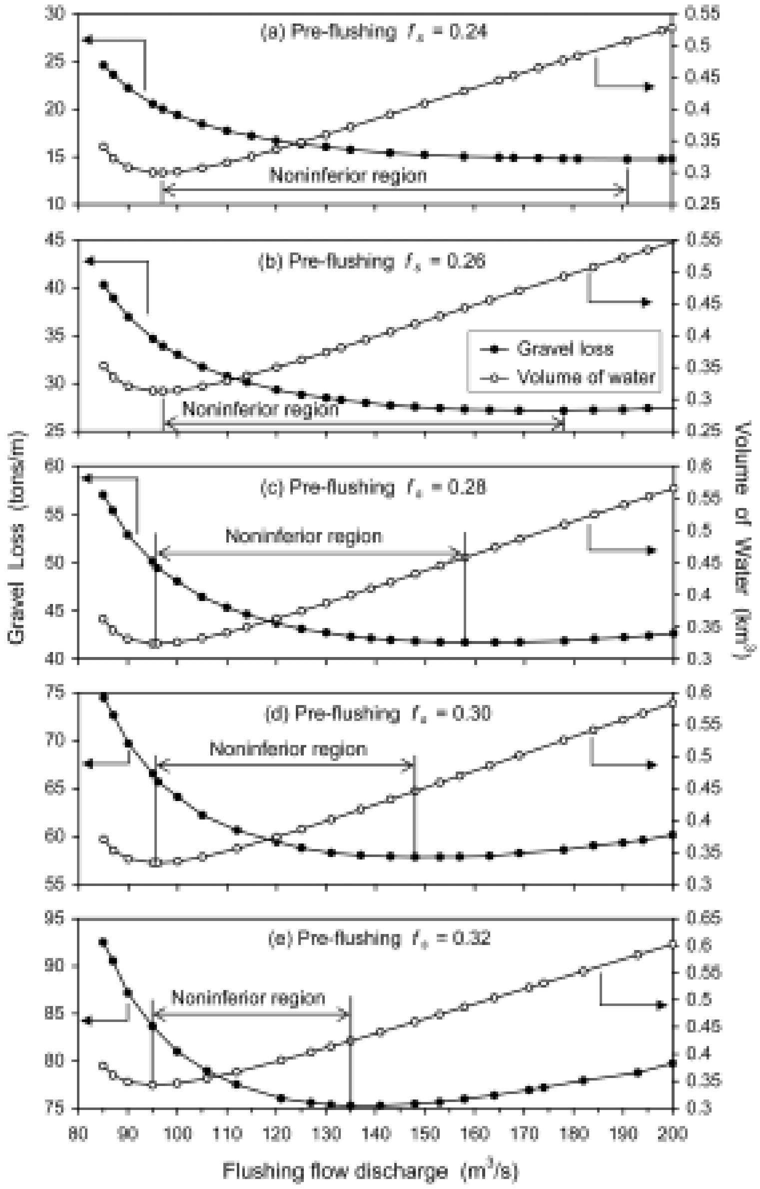

Figure 3. Variations of released water volume and total gravel loss with flushing flow discharge for pre-flushing f_s = (a) 0.24 (b) 0.26 (c) 0.28 (d) 0.30 (e) 0.32 (Noninferior options in the decision space are demonstrated.)

2.3 Gravel Loss vs. Flow Discharge

The total loss of gravel in the simulation reach is evaluated by summing up the difference between the gravel outflow from sub-reach 3 and the gravel inflow to sub-reach 1 over the entire flushing duration. The relationships between total gravel loss and flushing discharge (Figure 3) reveal that the gravel loss does not monotonically decrease with the flow discharge. Instead, the gravel loss decreases first and then slightly increases with the flow discharge. As the pre-flushing f_s value increases from 0.24 to 0.32, the flow discharge corresponding to the minimum gravel loss decreases from 191 to 135 m^3/s (Figure 3). The flushing flows corresponding to the minimum water consumption and gravel loss are given in Figure 4a, where the flows for the minimum water consumption (with an average = 96 m^3/s) are less variable than those for the minimum gravel loss. Moreover, both the minimum water consumption and gravel loss increase with the pre-flushing f_s value (Figure 4b), implying that higher costs are associated with the greater amount of sand to be removed (i.e., the worse bed sediment condition).

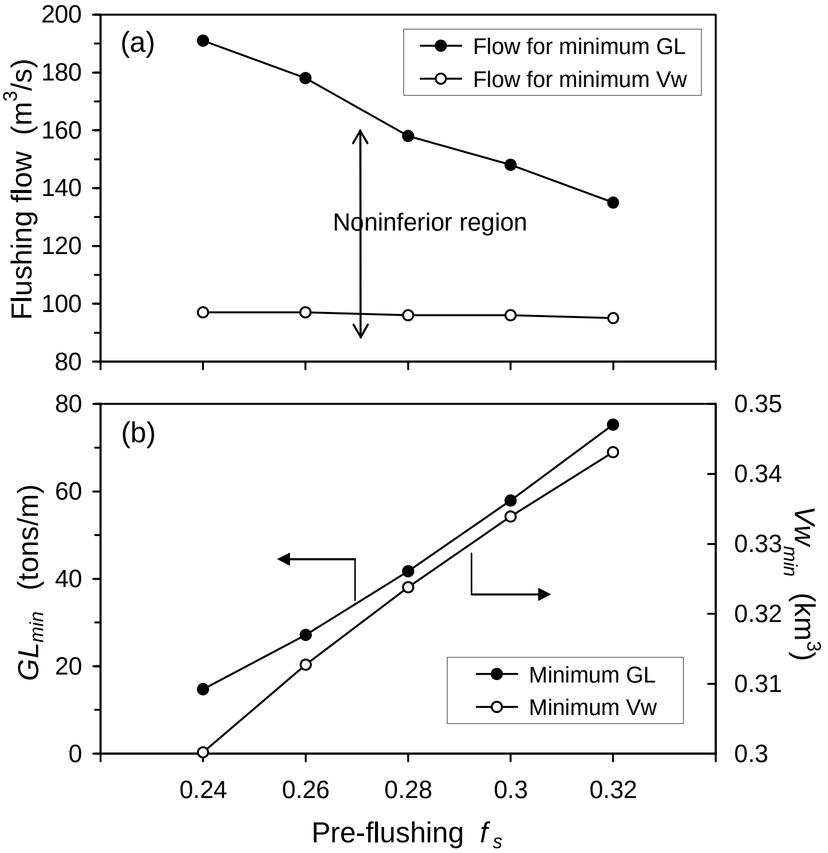

Figure 4. Variations of (a) Flows corresponding to minimum gravel loss and water volume (b) Minimum gravel loss and water volume with pre-flushing f_s value

2.4 Noninferior Flushing Options

It is easily verified that for any two convex curves, such as the ones for water volume and gravel loss (Figure 3), every point between the flows corresponding to the minimum water volume and gravel loss is a noninferior solution in the decision space. In the noninferior regions (Figure 3), a decrease in gravel loss is achieved at the cost of an increase in water volume, and vice versa. Out of these regions, the flow options become inferior because the gravel loss and water volume increase simultaneously. It is demonstrated that the noninferior region becomes smaller for the higher pre-flushing sand content (Figures 3 and 4a), implying that the feasible options are constrained in a narrower range if there is more sand to be removed. Because these noninferior flows are greater than ~100 m^3/s, the corresponding flushing durations are less sensitive to the flow discharge, as described previously (Figure 2). For these noninferior flows the flushing duration may be taken as a less restrictive criterion, thus the original tri-objective system may be simplified as a bi-objective one.

To be more useful, the noninferior options in the decision space (Figure 3) are transformed to the feasible solutions in the objective space (Figure 5), where the water volume ratio $Vw/Vw_{\min}$ is defined as the released water volume divided by the minimum water volume, the gravel loss ratio $GL/GL_{\min}$ is the total gravel loss divided by the minimum gravel loss ($Vw_{\min}$ and $GL_{\min}$ given in Figure 4b). The results shown in Figure 5 are similar to the Pareto optimal frontiers typically used to demonstrate the noninferior solutions. Any point on the frontier represents a feasible combination of gravel loss and water volume, and their corresponding noninferior flushing flow can be found in Figure 3. Figure 5 also quantitatively displays the tradeoffs between the conflicting objectives. This, once again, highlights that under a worse bed sediment condition the feasible combinations of released water volume and total gravel loss (or the noninferior flushing options) are subject to more restrictions.

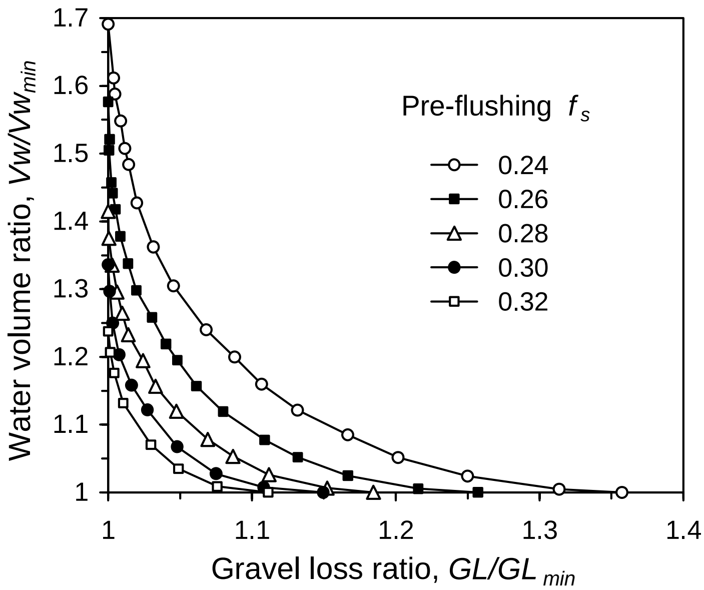

Figure 5. Tradeoffs associated with the feasible combinations of released water volume and total gravel loss under various pre-flushing f_s values (Noninferior options in the objective space are demonstrated.)

3. Conclusions

The simulation approach presented in this paper has general applicability to other sites, not for the merits of any individual step, some of which are obviously site-specific, but for the manner in which the integrated procedures permit exploration of the noninferior flushing options and a quantitative analysis of the tradeoffs associated with different flushing flows that is appropriate to the level of data typically available.

4. References

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計畫成果自評

本研究成果已被接受刊登於國際知名河川生態學術期刊 *River Research and Applications* (SCI)

可供推廣之研發成果資料表

□ 可申請專利　√ □ 可技術移轉　　　日期：92 年 11 月 03 日

國科會補助計畫	計畫名稱：鮭魚產卵礫石河床最佳沖淤水流之研究 計畫主持人：吳富春 計畫編號：NSC 91－2313－B－002－340　學門領域：農機
技術/創作名稱	沖淤水流規劃模式
發明人/創作人	吳富春
技術說明	中文： 本研究利用礫砂河床沖淤數值模式探討非劣勢沖淤方案與其協商值。模擬結果顯示沖淤效率隨流量而增大，但流量超過100m^3/s後流量之敏感度降低，沖淤系統可簡化為雙目標系統。礫石損失量與沖淤水體積為互斥結果。當河床泥砂條件較差時，可行方案較為受限並且花費較高。本研究將互斥結果之協商值以目標空間可行解方式量化呈現。 英文： A simulation approach to evaluating flushing flows and exploring the tradeoffs associated with noninferior flushing options is presented. A two-fraction sediment routing model is used to simulate the gravel-sand bed response to flushing flows. A series of numerical simulations are carried out with a range of flows and pre-flushing bed sediment conditions. The results reveal that the flushing efficiency is higher for the larger flow. However, for flows greater than ~100 m^3/s the flushing duration is less sensitive to the flow discharge, thus the system may be simplified as a bi-objective one. The gravel loss and water volume are two conflicting outcomes within the noninferior flow region. Under a worse bed sediment condition, the feasible flushing options are constrained in a narrower range and also associated with higher costs. The tradeoffs between the conflicting outcomes are quantitatively displayed with the transformed feasible solutions in the objective space.
可利用之產業 及 可開發之產品	河川生態保育；鮭鱒魚類產卵棲地復育
技術特點	利用礫砂河床沖淤模式規劃最佳沖淤水流方案

推廣及運用的價值	利用最佳沖淤方案達到最大沖淤效率。 利用礫石損失量與沖淤水量協商值尋找非劣勢沖淤方案