Summary: The hydrological effects of the Eurasian beaver (*Castor fiber*) in a UK headwater catchment

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Introduction and research gaps

Beavers (Genus: *Castor*) are ecosystem engineers that build dams, impounding water and causing a cascade of interacting changes to water fluxes and storage. Few studies have quantified site-scale effects of beaver dams on the water balance (i.e. the quantity of water stored and moving from one place to another at a site at a particular time). Effects of beaver dams on low-flows and high-flows have been observed previously, but results are sometimes contradictory and underlying mechanisms are not well understood. For instance, do beaver dams increase or decrease low flows, and what are the relative roles of storage and release of water from beaver ponds themselves and adjacent groundwater storage? Little consideration has been given to the effects on average flows. Numerical modelling could help to fill such knowledge gaps, but an appropriately validated approach for representing beaver dams is was lacking until this work was completed. Moreover, the hydrological effectiveness of pond levellers, a method for reducing beaver pond water level while not compromising the ecological requirements of beavers, was not available until the completion of this study.

An increased understanding of how beaver dams cause their hydrological effects

This PHD thesis investigated the hydrological effects of beaver dams using 25-months of monitoring data from adjacent catchments in eastern Scotland, one with 28 beaver dams (165 ha) and another without beaver dams (58 ha). Field data were used to build, calibrate and validate coupled hydrological/hydraulic models (MIKE SHE / MIKE 11) representing a 418 m stream reach and 12.3ha of associated floodplain containing five beaver dams.

Model simulations were used to estimate that fluxes of stream water, mainly to floodplain soils, reduced stream discharges downstream of beaver dams causing average-flow reductions of approximately 29% and a median peak-flow reduction of 3% (range: +4% to -11%). Figure 1 illustrates how a beaver dam increased water levels in the channel causing flows onto the floodplain.

Figure 1. Beaver dam (top right) causes increased water levels and beaver canals (upstream and to the left of the beaver dam) allow overbank flow onto the floodplain. Overbank flow such as this also provides a substantial opportunity for water to infiltrate into the floodplain.

Beaver dams appeared to augment downstream low-flow discharges when they fell below the leakage rate through the dams (estimated to be 0.5 to 2.0 Ls^{-1}; note that this amount of flow is just a trickle!), but reduced low-flows above this threshold. An explanation for this, consistent with the model simulations, was that beaver dams raise the level of water in the stream generally causing a net loss to adjacent soils under most conditions. However, some slight leakage through beaver dams means that, at the lowest flows, the water released from beaver ponds maintains a trickle downstream even during dry conditions such as during the dry summer of 2018. Field data suggested a greater degree of peak flow reductions than model simulations (median: 26%; range: +6% to -58%). A particularly novel finding of this study was that model simulations suggested that the majority of the flood peak attenuation caused by beaver dams was provided, not by the extra water stored in the ponds themselves, but by additional water stored in the surrounding soils. This finding was corroborated (in calculations not included in the thesis due to time constraints) by calculations using field data that showed that the amount of measured attenuation could not be explained by the additional water stored in beaver ponds during events.

The most novel finding of this study was that soil permeability substantially modulated the hydrological effects of beaver dams (i.e. effects on low-flows, average flows and high-flows) with many of the effects of the dams decreasing in magnitude with as soil permeability was reduced in model scenarios. Beaver dam height and topography were already known to be important in modulating the effects of beaver dams. Figure 2 is a conceptual diagram illustrating how these factors interact to modulate the effects of beaver dams.

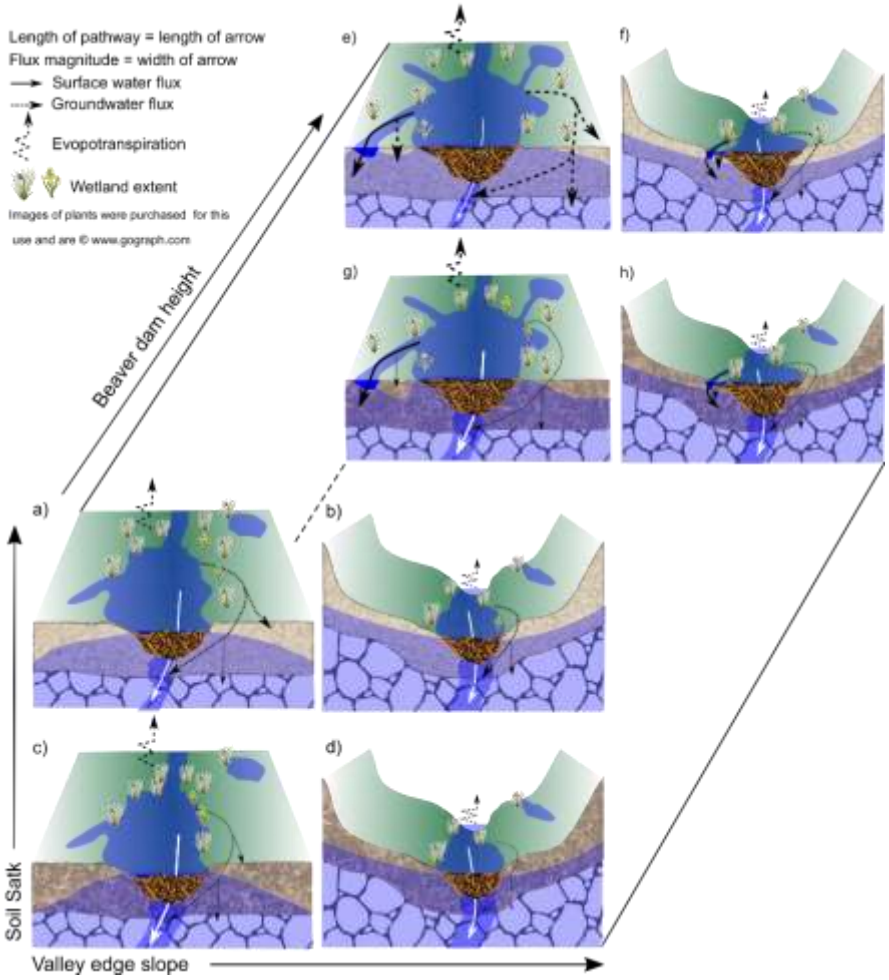

Figure 2. Conceptual model of the hydrological effects of beaver dams according to gradients of valley edge slope, Satk (saturated hydraulic conductivity), and effective beaver dam height. In all cases, stream inflows are median discharges (Q50) and the climate is the same.

How well do pond levellers work?

A pond leveller reduced the extent of the beaver pond studied substantially (~20cm reduction in water levels lead to a 57% reduction in a pond measured the current study for instance; Figure 3). However, inferences from field data and model simulations showed that when pond levellers were installed, the area with increased water levels beyond beaver ponds was still much more similar to the situation with beaver dams than without them. Therefore, pond levellers are probably an appropriate solution to reduce the beaver pond extent and but they should not be expected to reverse the effect of beaver dams in raising water levels on the adjacent floodplain.

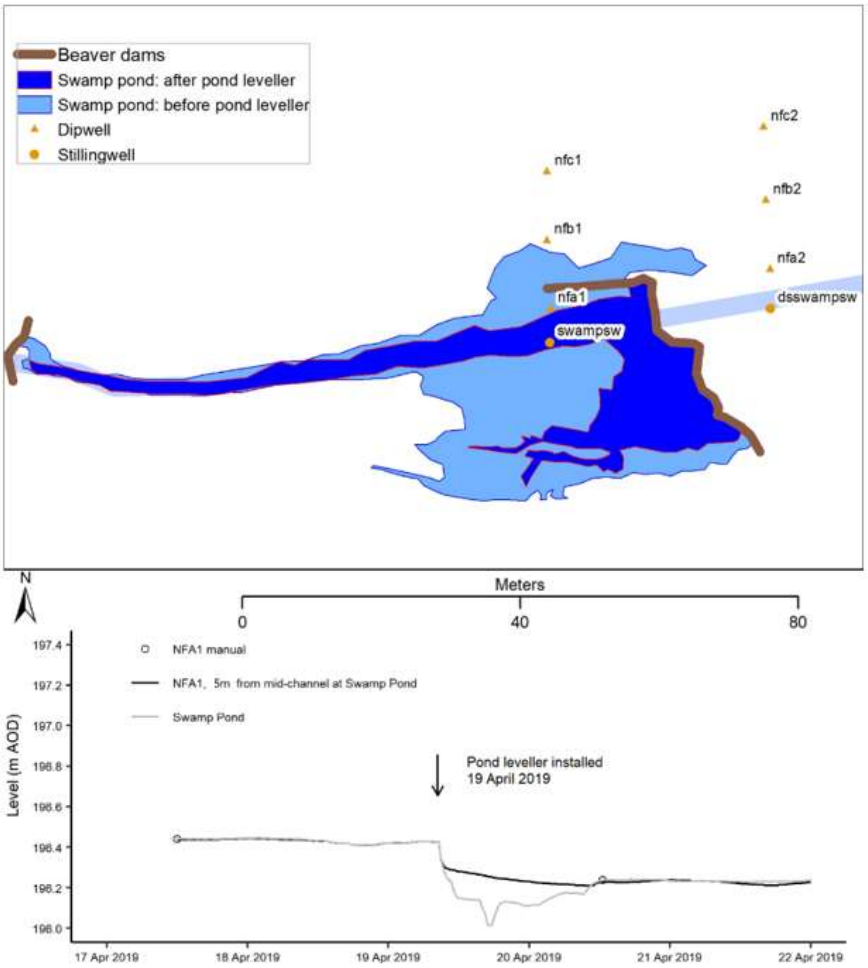

Figure 3. Comparison of beaver pond area on before (18 April 2019; 1367m^2) and after (20 April 2019; 585m^2) pond leveller was installed to reduce level. Stilling wells in the beaver pond (swampsw), downstream of it (dsswampsw), and dip wells upstream (nfa1-nfc1) and downstream (nfa2-nfc2) are also shown.

Summary and main implications

The key new finding of this study was a strong modulating effect of soil permeability on the hydrological effects of beaver dams. By changing the behaviour of an artificially incised stream from draining floodplain soils to partially irrigating them, beaver dams could help to restore floodplain wetland hydrology well beyond beaver ponds themselves. Model simulations showed that this effect was substantially greater with permeable floodplain soils and reduced with relatively impermeable soils. Model simulations of the main study site (Garage Field and surroundings) suggested that beaver dams caused a 32% increase in the area that had floodplain water levels (principally water table levels) high enough for a common wetland plant in the study area (*Glyceria maxima*). This "irrigation" came at the expense of slightly decreased downstream flows due to the water diverted onto the floodplain. Therefore, beavers have significant potential to restore hydrological conditions to headwater streams and floodplains that have been artificially drained thus supporting wetland restoration.

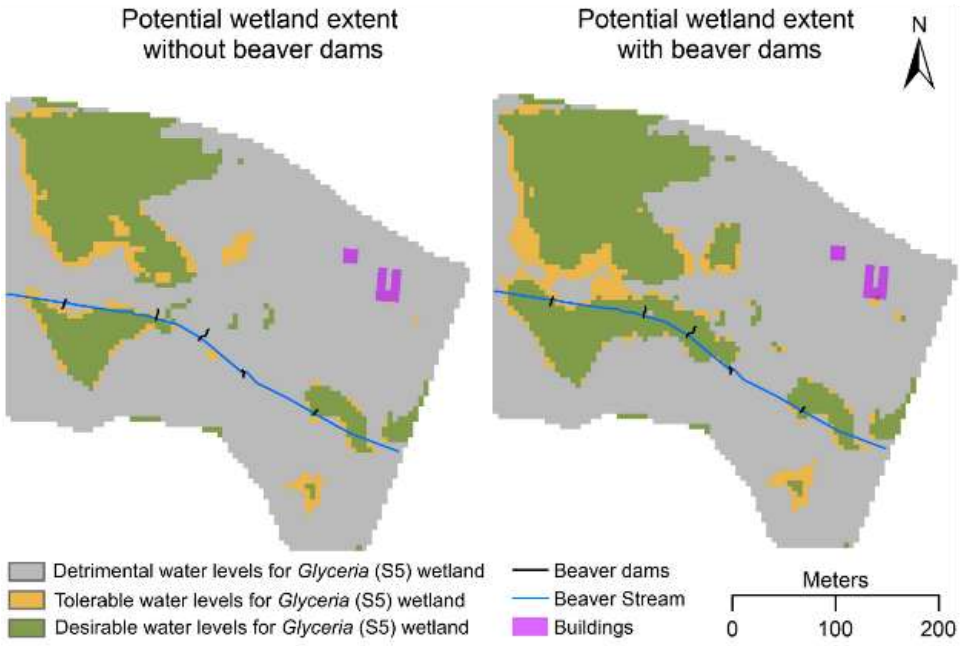

Figure 4. Comparison of areas that could potentially support a *Glyceria* (S5) swamp based on simulated water levels (groundwater or surface water) with and without beaver dams over the two year simulation period.

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