Chapter 2
The Necessity for Multidisciplinary Approaches to Wetland Design and Adaptive Management: The Case of Wetland Channels

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Abstract The need for a multidisciplinary approach to the design and adaptive management of constructed wetlands is illustrated by case examples of channel form and function in a variety of wetland types. Channels in wetland systems are typically viewed simply as conduits of water inflow and outflow. However, there are dynamic interrelationships amongst vegetation, hydrology/hydraulics, and substrate in wetland channel systems that demand a more holistic approach to wetland management that considers the disciplines of biology, engineering, and sedimentary geology. Recognition of the inter-dependence of the biologic, hydrologic, and geomorphic components of channelized flow in wetland systems is critical to the successful design of self-sustaining constructed wetlands.

For many wetlands, channelized flow is the predominant source of hydrology necessary to sustain the system. In other wetlands, channelized flow may be equally as important as groundwater and overland sheet flow as a water source. And, as wetlands can be defined by hydrology, vegetation, and soils, so are the form and function of wetland channels defined by the interrelationships of hydrology, vegetation, and soils.

In recent years, the practice of stream restoration has identified the need to integrate the sciences of engineering, biology, and geology in the application of fluvial geomorphology. This has been motivated by the less than stellar success rate for stream restoration projects. Too often the multidisciplinary nature of the natural system is lost by the dominance of one of these technical fields in the design of the restoration site. This can also be said of the design of channels in the practice of wetland construction for the purposes of restoration, enhancement, and creation.

Wetland channels serve as excellent examples of how important it is to engage multiple disciplines in the study of wetlands and the application of wetland science. On the surface, it might appear that channelized flows in wetlands are purely

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a matter for hydraulic engineers charged with designing a conduit to convey water. However, this could not be further from the truth. Channels in a wetland constrain the development of its biological character. Understanding how the bio-, hydro-, and geomorphic components of a channelized system in a wetland are inter-dependent and unique is essential if we are to design self-sustaining constructed wetland systems. When present, channels are lynch-pins in the holistic integrity of a wetland system.

The focus of this chapter will be to take a look at wetland channel morphology in a variety of wetland types to illustrate the inter-related contributions of geology, engineering, and biology to the understanding of wetlands. It is not intended to be a comprehensive synopsis of wetland channel knowledge, nor a literature review of wetland channel studies. The references cited in this chapter, in combination, will accomplish that. Its objective is to introduce the reader to the wide range of multidisciplinary linkages in wetland channel morphologies and functions so as to emphasize the need to incorporate a multidisciplinary approach to the design and adaptive management of wetland creation, enhancement, and restoration sites.

Many terms and classification systems are used to describe and define wetlands—swamp, marsh, bog, fen, peatland, mire, moor, muskeg, bottomland, wet prairie, reedswamp, wet meadow, slough, pothole, playa (Mitsch and Gosselink 2000). And, many terms have been used to refer to linear features of water conveyance in wetlands—streams, creeks, channels, and sloughs. The original terms used in the studies cited are maintained here. No attempt has been made to re-assign wetland types and terms to a single classification system.

Channels and Feedback Mechanisms

Wetland landforms display hydrology, vegetation, and soil characteristics distinguishable from non-wetland systems. Aside from land preservation or the regulation of activities that could directly or indirectly affect wetlands, wetland protection in the United States today is largely achieved by replacing wetland functions lost or diminished by some action. Channels in wetland functional analyses are typically viewed as conduits of water inflow and outflow. Similarly, when designing or monitoring channels in constructed wetlands, the focus is typically to size the conveyance of computed quantities of water into and out of the system. Channels however, play a role beyond serving as conduits delivering water and carrying it away.

When it comes to channels, there is a temptation to view alluvial rivers and their floodplains as templates for wetland channels and the marshes or swamps they pass through. However, as stated by Jurmu (2002, p. 832): "If wetlands are unique biologically, have distinct hydrology, and function unlike other environments, it follows that factors affecting streams (their function and characteristics) might also be distinct and create different morphological features." To this can be added that there is considerable variety in wetland types, hence, one can expect the variety in form and function of wetland channels to be similarly vast.

There is also a tendency to view wetland systems as static, and not evolutionary. Channels maintain the existing integrity of the system while simultaneously advancing changes which will lead either to continued sustainability or not. The feedback influences of biology, geology, and hydrology on one another create a changing system with time. When establishing protocols of adaptive management for constructed wetlands it is very important to understand how channel processes influence the temporal development of the wetland as a whole.

How do wetland properties influence channel form and how does channel form affect overall wetland hydrology? How does this vary among different wetland types? The scientific literature reveals a dynamic interrelated feedback amongst vegetation (biology), hydrology/hydraulics (engineering), and substrate (sedimentary geology). The fact of this inter-dependence demands a holistic approach to wetland management in general, and wetland construction in particular (Fig. 2.1). There is a need to integrate a developing school of thought within the disciplines of geomorphology and ecology that recognizes the imperative to integrate the physical and biological.

The recognition of the importance of the reciprocal interactions and adjustments of biotic (organisms and communities) and abiotic (form and process) components of our planet has been fundamental to the development of modern science in the nineteenth century (Corenblit et al. 2008). Landscapes develop as by-products of the feedback mechanisms between organisms and their habitats which are simultaneously dependent and controlling factors.

Geomorphic-biological feedback, the interactions between the geomorphic and ecological components of landscape, has often been viewed as independent pro-

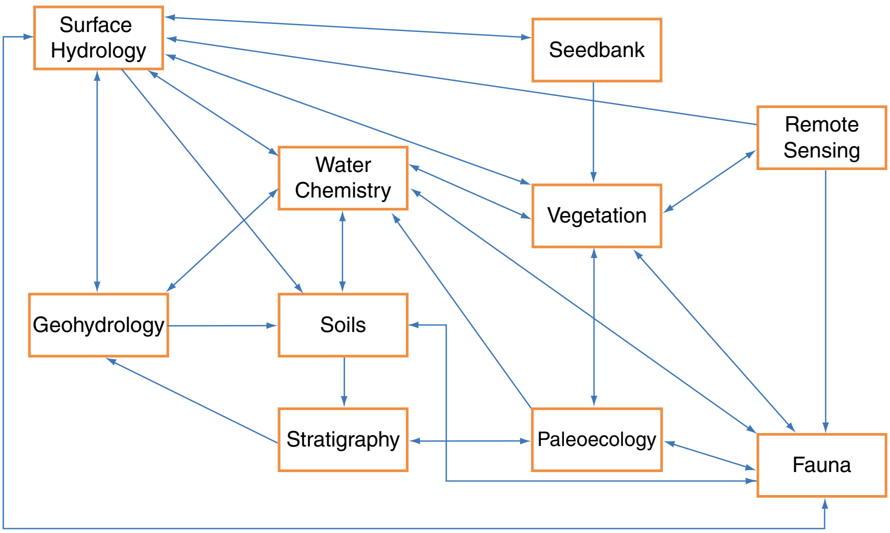

Fig. 2.1 Arrow directions indicate how different wetland disciplines can inform others. (After Wilcox 1987)

cesses operating in one direction (Stallins 2006). That is, the scientific literature provides many instances where, in one direction, geomorphic process and landscape are shown to influence biota or, in the other direction, the biota is shown to affect geomorphic process and landscape. This unidirectional precept, however, is being replaced with more complex, non-linear developmental and evolutionary theories wherein form and process evolves in accordance with biologic evolution, in the long term, and with ecological succession in the shorter. There is a long- and short-term developmental linkage and a cumulative feedback, a sort of bio-geomorphologic inheritance or memory.

Multiple Influences on Channel Morphology—Case Examples

When referring to channel morphology we must consider plan form and cross-section shape (Figs. 2.2 and 2.3). Fauna and flora are documented to have an influence on channel form and process, and vice versa. Case examples are provided below to demonstrate the wide range of channel bio-geomorphic and hydro-geomorphic feedback mechanisms to be found in many wetland types. It is not intended to be

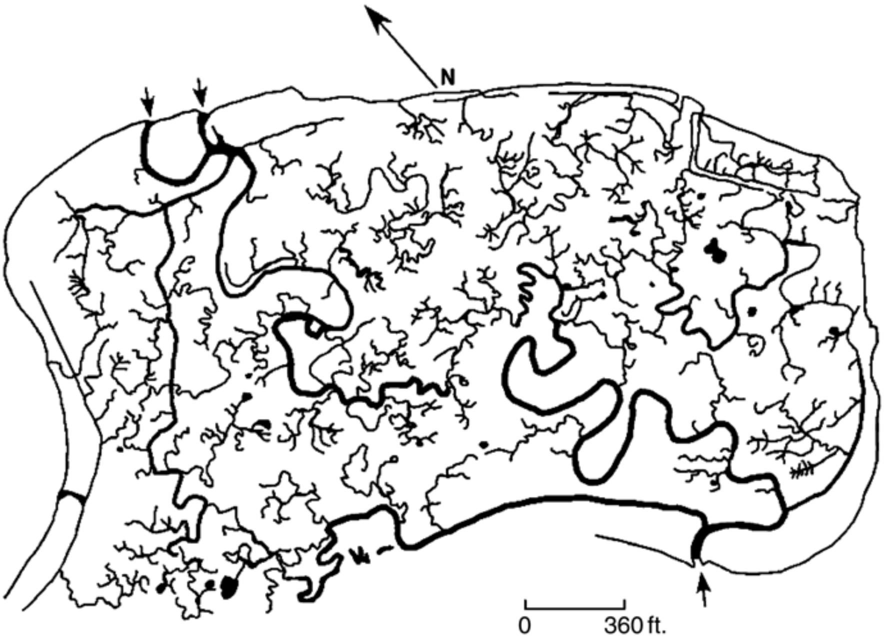

Fig. 2.2 Channel distribution in natural tidal marshes illustrating the complex plan form morphometry of a channel system in a tidal marsh of San Francisco Bay. Varying morphometric parameters include order, sinuosity, drainage density, and junction angle. Arrows indicate major channel inlets/outlets. (Redrawn and modified from Pestrong [1965])

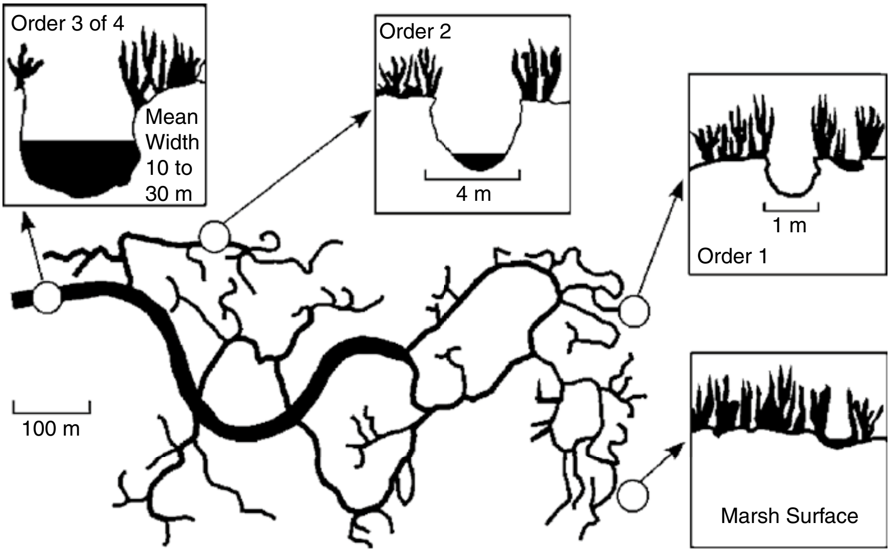

Fig. 2.3 Creek network illustrating how channel cross-sectional morphometry (e.g., width:depth ratio) and hydrology vary with position in the system. The insets illustrate the typical profiles and widths of the creeks and water levels at low tide. The third and fourth order creeks retain most of the water volume at low tide, while the second order creeks retain shallow pools at low tide. The first order creeks and marshes drain completely at low tide. (Re-drawn and modified from Williams and Desmond [2001])

exhaustive, but rather to provide support for the approach to wetland construction design and adaptive management to be discussed subsequently.

Vegetation has been the focus of most bio-geomorphic feedback investigations with respect to wetland channels, particularly the effect on flow of increased bank strength and hydraulic roughness from vegetation along channel margins. Jurmu (2002) suggests this might lead to the low width:depth ratios (relatively narrow and deep) of stream reaches passing through palustrine wetlands (emergent, scrub–shrub, forested) in Connecticut, Indiana, and Wisconsin. In these cases, channel shape adjusts to flow variability by bed erosion and deepening rather than lateral channel migration that is prevalent in alluvial channels.

In tidal San Francisco Bay, channel sinuosity is higher in salt marshes, where the vegetation is a dominant feature, than on adjacent unvegetated tidal mudflats (Pestrong 1972). In New Jersey, USA higher channel sinuosity has been found in tidal salt marshes with dense and extensive root systems in peaty substrates than in tidal freshwater marshes with sparse root systems in muddy substrates (Garofalo 1980). Channel morphology is influenced more by hydrodynamic factors in the freshwater tidal marshes while vegetation is more important in the salt marshes.

In southern Africa's largest wetland, root density and root attachment to a peaty substrate influences channel form and function in a very different way (McCarthy and Ellery 1997; Ellery et al. 2003; Tooth and McCarthy 2004). In Botswana, the

Okavango River and its distributary channels support permanent and seasonal floodplain swamps of emergent grasses and sedges by overbank flooding and water leakage through channel margins. In contrast to alluvial streams, the discharge through these channels progressively decreases downstream due to a combination of water loss to distributaries, overbank flow, and bank leakage. When bank overtopping reduces channel discharge enough to allow *Cyperus papyrus* (papyrus sedge or paper reed), a semi-floating unattached mat of entangled rhizomes to encroach into the channel, channel width is reduced. Water flow velocity is reduced as the constriction is approached, and water is rapidly lost from the channel as water levels rise above the surrounding swamp above the constriction. With the high hydraulic conductivity afforded by this plant species, there is even more water loss from the channel at the margins. As velocities decrease, bedload transport declines, sediments deposit, and the channel aggrades. The biology–morphology–hydrology feedback eventually leads to channel in-filling, avulsion, and abandonment.

Biology–morphology–hydrology feedback can be subtle to discern, but is no less important to the understanding of the sustainability of a wetland. This can be seen in the case of channels through peatland fens in Wisconsin and Canada.

Watters and Stanley (2007) investigated the cross-section and plan form morphology of a stream flowing through an extensive fen in Wisconsin, USA. Over 90% of total stream flow is groundwater base flow, thus, channel discharge variability is low and overbank flooding is rare. Vegetation near the stream is mostly hummock-forming sedges. An organic channel bed substrate prevails in the fen; an inorganic, mineral substrate outside the fen. An interesting characteristic of the fen channel cross-section is a shallow side with loose organic sediments (highly decomposed with 25–50% organic content) and a deeper side with firm peat (90% organic content with limited decomposition). The shallow sides are zones of groundwater discharge. Thus, peat dynamics, dominated by groundwater hydrology, dictate plant decomposition and peat quantity and quality (fiber content, susceptibility to decomposition, and bulk density). All this is linked back to channel morphology.

One can extend the biofeedback concept through time whereby the biologic mechanisms affecting channel form are past processes. This is exemplified by the case of distributary channels in the Cumberland Marshes in Canada (Smith and Perez-Arlucca 2004). Here, channels are incising through peats produced by old fens. Fen peatlands originally occupying alluvial floodplains were converted to shallow basins after being flooded by the avulsion of a main channel. Distributary channel networks developed over a wedge of avulsion sediment that covered the peats. Downcutting channels may eventually encounter the pre-avulsive peat. Channels with peat bottoms tend to have rectangular cross-sections, higher width:depth ratios, and higher average:maximum depth ratios than channels that have not yet reached the peat, or have completely eroded through it. This suggests that when encountered, the peat promotes the accommodation of increasing discharges by enlarging through channel widening rather than deepening. This is a biologic influence on channel shape that is temporally disjointed from current processes.

An informative way to add flow to the equation to see how channel shape adjusts to changing flow regimes is to assess hydraulic geometry, relating changes in discharge to rates of change in channel width, depth, and velocity. The hydraulic geometry relationships for a wide range of tidal and non-tidal wetland types demonstrate the variety of channel responses to hydrologic forces (Myrick and Leopold 1963; Zeff 1988; Leopold et al. 1993; Tooth and McCarthy 2004; Watters and Stanley 2007; Diefenderfer et al. 2008; Nanson et al. 2010).

Nanson et al. (2010) identify an interesting hydraulic geometry relationship in peatland swamps of Australia. Channel banks are nearly vertical with high bank strength provided by grass- and tussock-rooted peat. Channels remain relatively narrow and deep in these swamps, reflected in low width:depth values. However, the hydraulic geometry relations indicate that these channels accommodate increases in discharge by increasing flow velocity rather than adjusting channel dimensions. Bankfull flows are frequent enough to maintain high enough water tables to support the wetland vegetation, however, bankfull flows are quickly moved through the channels and overbank flooding is rare. Vertical growth of the wetland is limited and linked to channel depth.

Channels in Wetland Design and Adaptive Management

It should be evident from the few cases cited above that, when designing channels for constructed wetlands, one needs to consider more than the hydrology/hydraulics concern for sizing to convey predicted design discharges. As illustrated in these studies, channels will accommodate changes in flow regime by adjusting shape, or velocity. And, the channel response to process alterations will be unique to the biogeomorphology and hydrogeomorphology of the particular wetland.

Predicting how these adjustments will impact the short-term success and long-term sustainability of a constructed wetland requires a robust multidisciplinary understanding and application of site-specific feedback mechanisms of biology, hydrology/hydraulics, and sedimentary geology. And, to establish when adaptive management is appropriate, the short-term and long-term integrity of the entire wetland system needs to be evaluated with respect to intrinsic evolution and extrinsic forces. For example, do we need to interfere with sedimentation in a channel if infilling and avulsion is a process-response necessary for continued existence of the wetland system? What can be done to protect a restored salt marsh from drowning if vertical accretion is not keeping pace with sea level rise?

The multidisciplinary approach needed is really an interdisciplinary approach. Wilcox (1987) noted that the scientific studies of various disciplines regularly involved in wetland research are often narrow in focus and there is a danger in extrapolating these limited scopes to broader wetland issues. He encouraged the collective interpretation of data from multiple disciplines. This holds true for constructed wetland and post-construction management as illustrated by the case of the wetland channels.

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