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The role of wetlands in the hydrological cycle

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Abstract

It is widely accepted that wetlands have a significant influence on the hydrological cycle. Wetlands have therefore become important elements in water management policy at national, regional and international level. There are many examples where wetlands reduce floods, recharge groundwater or augment low flows. Less recognised are the many examples where wetlands increase floods, act as a barrier to recharge, or reduce low flows. This paper presents a database of 439 published statements on the water quantity functions of wetlands from 169 studies worldwide. This establishes a benchmark of the aggregated knowledge of wetland influences upon downstream river flows and groundwater aquifers. Emphasis is placed on hydrological functions relating to gross water balance, groundwater recharge, base flow and low flows, flood response and river flow variability. The functional statements are structured according to wetland hydrological type and the manner in which functional conclusions have been drawn. A synthesis of functional statements establishes the balance of scientific evidence for particular hydrological measures. The evidence reveals strong concurrence for some hydrological measures for certain wetland types. For other hydrological measures, there is diversity of functions for apparently similar wetlands. The balance of scientific evidence that emerges gives only limited support to the generalised model of flood control, recharge promotion and flow maintenance by wetlands portrayed throughout the 1990s as one component of the basis for wetland policy formulation. That support is confined largely to floodplain wetlands, while many other wetland types perform alternate functions — partly or fully. This paper provides the first step towards a more scientifically defensible functional assessment system.

Keywords: wetlands, hydrological functions, flood reduction, groundwater recharge, low flows, evaporation

Introduction

Open any book on wetland conservation and it will encourage the maintenance of wetlands partly because of their role in the water cycle. Wetlands are said to perform “hydrological functions”; to “act like a sponge”, soaking-up water during wet periods and releasing it during dry periods (eg. Bucher *et al.*, 1993). As Maltby (1991) reports “… the case for wetland conservation is made in terms of ecosystem functioning, which result in a wide range of values including groundwater recharge and discharge, flood flow alteration, sediment stabilization, water quality …..”. Since wetlands cover around 6% of the land surface of the earth (OECD, 1996) and many exist in the upstream parts of river catchments, the total downstream area over which a hydrological influence may be exerted is substantial. Yet the hydrological processes and behaviour of wetland ecosystems has certainly lacked the scientific integration received by other land surface systems, such as forests. Kusler and Riexinger (1985) reported that “the science base and efforts to assimilate existing studies are still inadequate with regard to some functions, particularly hydrology”.

The basic references on the hydrological functions of wetlands are summaries of studies collated in the USA in the 1980s (Adamus and Stockwell, 1983; Bardecki, 1984; Carter, 1986). These summaries have been used by organisations, such as IUCN-The World Conservation Union (Dugan, 1990), Wetlands International (Davis and Claridge, 1993) and the Ramsar Convention on Wetlands of International Importance (Davis, 1993). They have influenced international wetland policy (OECD, 1996) and its uptake at the national (eg. Zimbabwe and Uganda), and continental levels e.g. Europe (CEC, 1995) and Asia (Howe *et al.*, 1992).

Recent emphasis at the Second World Water Forum in The Hague 2000 and the World Summit on Sustainable Development 2002 in Johannesburg was placed on the need to ensure the integrity of ecosystems as part of integrated water resources management. Also receiving high prominence was the use of water to meet basic human needs and economic development. Thus, it is essential to re-examine, periodically, the conclusions of scientific studies on wetland functions. This ensures that policy at all levels is underpinned by a consensus of sound scientific opinion.

The scientific literature contains a range of studies that describe the water quantity functions of individual or groups of wetlands. They represent a substantial accumulation of hydrological knowledge. The majority of these papers supports the notion that wetlands have a significant influence on the hydrological cycle. However, many recognise that "it is difficult to make definitive statements regarding the role of various types of wetlands in runoff production or storm water detention" (Carter, 1986). Furthermore, some studies have produced evidence that contradicts previous widely accepted knowledge. For example, the classic hydrological studies of Hewlett and Hibbert (1967) identified headwater wetlands along river margins as flood generating areas. Burt (1995) concluded that "… most wetlands make very poor aquifers; ... accordingly, they yield little base flow, but in contrast, generate large quantities of flood runoff. Far from regulating river flow, wetlands usually provide a very flashy runoff regime".

This paper has three objectives: first, to present an ordered database of published papers on hydrological functions of wetlands; second, to provide a collation of scientific evidence among hydrological measures and wetland type; third, to stimulate debate and further research. The focus of this paper is limited to water quantity functions, including impacts on water resource availability, groundwater replenishment and flood control. It does not consider other aspects of wetlands, such as water quality or biodiversity, which are part of a wider case for wetland conservation.

Creating a literature-based review of water quantity functions

With the objective of creating a comprehensive and consistent database of past studies, a literature review of water quantity functions was undertaken by keyword searches on the major databases of abstracts, and by tracking citations to earlier and related studies. Consequently, the database is drawn from 169 publications that report the results of scientific study that quantify hydrological functions of wetlands. Papers that report other authors' findings or give only qualitative descriptions of wetland process are not included.

Certain guidelines were followed, namely that:

- the review is restricted to freshwater wetlands, excluding lakes;
- conclusions of wetland function must be supported by hydrological data and not based on the original author's opinion alone;
- double-accounting is avoided, whereby repetition of conclusions for an individual wetland in successive publications is not duplicated;
- unsubstantiated generic statements, such as wetlands reduce flooding, are not included.

Consistency is ensured by extracting common elements from the diverse sources. Important information is maintained in the detail of the particular hydrological function, wetland type and the manner of conclusion. The approach adopted was to complete the following general statement (where bracketed and underlined phrases relate to elements in Annex 1) for each study:

"(**Author(s)**) undertook a study in a given location (**country**, or US State/Canadian Province or Territories) of a particular hydrological type of wetland (**wetland type**), also referred to by a more general or locally-specific wetland term (**local term**). Based on results from a particular type of study (**categorisation of wetland study**) and drawing inferences in a particular manner (**basis of inference)**, the authors conclude (**page number**) that the wetland performs a particular function with respect to a specific hydrological measure (**hydrological measure**), as can be summarised by a functional statement (**summary functional statement**) and a summary function (**summary of wetland water quantity function**)".

There are, therefore, ten elements extracted from each publication, each entered into the database. Explanation of each of these elements is expanded upon below. Because the format of the review is tabular, abbreviated codes are adopted for some elements for purposes of brevity.

Author(s): Citation to original source.

Country, or US State/Canadian Province or Territories: Location of wetland study.

Wetland type: For the purpose of this study, wetlands are categorised into five types according to three broad hydrological features (Table 1), based, with modification, upon the scheme proposed by Novitski (1978) for Wisconsin wetlands and subsequently applied by Adamus and Stockwell (1983). The three hydrological features are general catchment location, connectivity with the groundwater system and connectivity with the downstream channel network. General catchment location distinguishes

Table 1. Categorisation of wetland type by hydrological features

Type	*Wetland type*	*Code*	*Features*
Headwater	Surface water depression	SW/D	No hydraulic connectivity with groundwater. Outlet has no direct connectivity with river system
	Surface water slope	SW/S	No hydraulic connectivity with groundwater. Outlet has direct connectivity with river system
	Groundwater depression	GW/D	Hydraulic connectivity (permanent or periodic) with groundwater. Outlet has no direct connectivity with river system
	Groundwater slope	GW/S	Hydraulic connectivity (permanent or periodic) with groundwater. Outlet has direct connectivity with river system
Floodplain	Floodplain	FP	Inputs are dominantly upstream river flows
General			Wetland type, or one element of the type, cannot be specified

between headwater and floodplain; the distinction is that headwater wetlands are not fed by significant stream sources. Further subdivision applies only to headwater types. The connectivity with the groundwater system distinguishes 'groundwater' types that are in hydraulic connectivity with the groundwater system for all, or part of, the time, from 'surface water' types, which are not. Connectivity with the downstream channel network distinguishes 'slope' types, which are characterised by an outlet to the downstream river system, from 'depression' types, which are not. This categorisation deviates from that of Novitski and Adamus and Stockwell by including a floodplain type and in the 'surface–slope'type which, in that scheme, categorises lakeshore wetlands. Therefore, the two schemes are similar but are not directly comparable. An unspecified category is added, and applied where the hydrological context of the wetland cannot be discerned.

Local term: Many local terms are applied to wetlands, including such general anglicised terms as 'marsh', 'swamp', 'bog' etc, and regionally specific terms such as dambo, pakihi, pocosin. There is no known means of providing a direct association between local terms and hydrological type in a fully inclusive manner.

Categorisation of wetland study: Wetland studies have adopted a number of experimental frameworks, ranging from intensive long-term monitoring of the water balance of wetland and non-wetland at the most complex extreme, to analyses based on single flood event hydrographs. Table 2

Table 2. Categorisation of methodological approach to wetland studies

Category of wetland study	*Code*	
Conceptual catchment model	CCM	Calibration and application of a conceptual catchment model
Water balance	WB	Quantification of the terms of the catchment and/or wetland water balance
Long-term hydrograph	LTH	Analysis of the characteristics of long time series of river flows
Single-event hydrograph	SEH	Analysis of the characteristics of a single river flow event
Trend analysis in time series	TS	Analysis of trends in hydrological time series (associated with detecting the impacts of drainage)
Component process	$COMP_a$	Investigation of an individual water balance component or hydrological process. (See Table 4 for definitions of 'a')
Chemical balance	CHEM	Quantification of a chemical process or chemical balance

presents categories of methodological approach with abbreviated codes for brevity in the tabular review.

Basis of inference: Many studies draw conclusions of the kind that, for example, wetlands reduce floods or augment dry season river flows. This kind of conclusion, when taken out of context, leaves unanswered the basis for that conclusion, notably that the wetland reduces (or increases) river flows — compared with what? Table 3 presents a set of the comparative scenarios used amongst the various

Table 3. Basis for inference of wetland function

Code	*Baseline for inference*	*Methodology*	*Limitations*
With/out	Comparison of the same basin, with or without a wetland	This approach is restricted to catchment model simulations, in which the model is calibrated in either the "with" or "without" wetland case, as occurs in the modelled catchment. Model runs with the wetland case reversed generate simulated hydrological outputs. Differences between observed and simulated outputs are attributed to the presence of the wetland.	One case is simulated only. Stability of model parameters. Response of wetland replacement zone.
Drained	Comparison of the same wetland basin before and after drainage; or neighbouring drained and undrained wetlands	Hydrological outputs from a wetland are observed prior to drainage. The wetland is drained, and outputs are observed after drainage. Differences in the pre- and post- drainage outputs are attributed to the wetland. alternately, outputs from two adjacent catchments, each with wetlands, are observed. One of the catchments is drained, and differences between the outputs between the two catchments are attributed to the presence of the wetland.	Response of replacement land-use in drained wetland. Initial short-term responses to drainage may differ from long-term responses.
Pair	Comparison of paired basins, one with wetland the other without	Hydrological outputs are observed from two catchments, similar in all respects except that one that one catchment contains a wetland while the second does not. Differences between the outputs are attributed to the presence of the wetland.	If two catchments are otherwise identical, why does only one have a wetland?
Multiple	Comparison of several basins with varying proportions of wetland	Hydrological outputs are observed from several catchments, each containing different proportions of wetland. Differences between the outputs are attributed to greater or lesser presence of wetland.	Variability in non-wetland characteristics amongst several catchments
In-out	Comparison of inflows and outflows of a wetland system	Hydrological inputs and outputs associated with a single wetland are measured. Differences between inputs and outputs are attributed to the presence of the wetland.	
Same	Comparison of wetland hydrological response with response elsewhere in the same basin	Hydrological outputs from a single wetland are measured as well as outputs from other non-wetland portions of the same catchment. Differences between the outputs are attributed to the wetland.	
$Comp_a$	Conclusions relating to individual components of the wetland through the development of an understanding of a component process	Individual component processes are observed and understood within a single wetland. The understanding of the processes is the basis for inferring the influence of that process on the hydrological output. (Substituting for $_a$: T = topography, V = vegetation, S = Soil, WC = water content, GW = groundwater, ET = evaporation)	Extrapolation of a single process in isolation. Processes may not be homogeneous across the entire wetland.

publications as the basis for inferring wetland function. Each basis has some limitations, and these are summarised. Again, abbreviated codes are set out.

Page number: Page number in the original publication on which the conclusion is drawn.

Hydrological measure: There are many different measures in hydrology to describe and define aspects of the flow regime. While non-hydrologists might refer generically to floods, the hydrologist would be concerned with measures such as the magnitude of the peak flow during the flood event, the volume of runoff contained in the event, and the time-to-peak. Published studies in wetland hydrology are not consistent in their attention to different measures; it is possible to find one study analysing the return period of flood peaks extracted from a 20 or 30 year flow record, and another analysing the flood volume of a single event, with both drawing conclusions on wetland influences on floods.

Table 4 presents and defines different hydrological measures within five broad groupings of hydrological response, namely; gross water balance, groundwater recharge, base flow and low flows, flood response and river flow variability, including some seasonal variations.

Summary of wetland water quantity function: Conclusions regarding water quantity functions extracted directly, or in paraphrased form, from the original text are presented.

Summary functional statement for hydrological measure: Functional statements of the form 'wetlands increase low flows' are expressed as the sign of the wetland influence upon the hydrological measure; thus '+' indicates an increasing influence upon the hydrological measure, '-' indicates a reducing influence and '.' represents a neutral influence (i.e. no significant influence exists or can be detected). In the case of groundwater recharge and groundwater discharge sites, there is interest in the conservation-based literature whether either of these functions is, or is not, present in a wetland. Therefore, '=' indicates that this function is present and 'x' indicates that it is not.

Global data base of wetland water quantity functions

The first objective of this paper is to redress the deficiency in availability of hydrological information on wetland functions by providing an accessible and consistent database of past studies. Annex 1 presents the product of the application of the global review. The database is composed of 169 different published studies with 440 functional statements, representing the fullest sample of studies that could be traced, conforming to the principles adopted. It would not be claimed that the sample is exhaustive, but it is considered to be comprehensive.

BALANCE OF SCIENTIFIC EVIDENCE FOR PARTICULAR HYDROLOGICAL MEASURES

Table 5(a to e) collates the number of functional statements for each wetland type for the five principal groups of water quantity measures. For example, interpreting Table 5a for floodplain-type wetlands, two studies conclude that an example of this wetland type increases mean annual flow, two studies concludes that no significant influence can be detected and eight studies conclude that examples of this wetland type reduce mean annual flow. Total numbers of functional statements are presented across all hydrological measures and all wetland types.

Analysis of the "balance of scientific evidence" draws on comparison of the number of papers that conclude a particular function. This is seen to be an important step and a precursor to more detailed exploration of the evidence for particular measures for specific wetland types. The results cannot yet be considered to reflect a "balance of scientific opinion", because there has been no inter-comparison amongst the different studies.

There are some cautionary perspectives and some limitations on the comparison that must be stated.

(1) The number of papers reporting a particular influence on the water cycle does not necessarily indicate the total picture. Some hydrological functions have been studied more than others.
(2) The number of functional statements cannot be interpreted as the number of wetlands performing a function; for example, a functional statement based on multiple catchments commonly involves a large number of individual wetlands.
(3) There is no certainty that the 169 publications represent all past studies of wetlands Although not exhaustive, the sampling method has been applied independently of any initial bias associated with policy interests. However, it cannot be discounted that there is potential bias in the wetlands that were selected for study by the original authors.
(4) The distribution of wetland types within the sample of reviewed studies does not represent the distribution of wetland types worldwide; this is particularly true given

Table 4. Hydrological measures and their definition

CODE	*Hydrological measure*	*Definition*
Gross water balalnce		
MAF	Mean annual flow	Volume (or rate) of river flow during a year (on average)
MAAE	Mean annual actual evaporation	Volume (or rate) of evaporation during a year (on average)
WPF	Wet period flow	Volume (or rate) of river flow during, or in response to, periods of rainfall
WPAE	Wet period actual evaporation	Volume (or rate) of evaporation during, or in response to, periods of rainfall
DPAE	Dry period actual evaporation	Volume (or rate) of evaporation during periods without rainfall
	Dry period flow	See 'DPFV' - Dry period flow volume
Groundwater recharge		
AGR	Annual groundwater recharge	Volume of water moving vertically from the wetland into the underlying groundwater system during a year
WPGR	Wet period groundwater recharge	Volume of water moving vertically from the wetland into the underlying groundwater system during, or in response to, periods of rainfall
DPGR	Dry period groundwater recharge	Volume of water moving vertically from the wetland into the underlying groundwater system during periods without rainfall
Base flow and low flows		
GDS	Groundwater discharge site	Movement of groundwater into surface water through the wetland
DPFV	Dry period flow volume	Volume of flow during dry periods
DPFD	Dry period flow duration	Duration for which flow is sustained during dry periods
DPRR	Dry period recession rate	Rate of flow recession during periods without rain; a high rate indicates a rapid decrease in flow, a low rate indicates sustained low flows
Flood response		
FPLM (T <2 years)	Flood peak of low return period	Peak flow during a flood event, where the flow is exceeded on average every two years or less
FPHM (T > 2 years)	Flood peak of high return period	Peak flow during a flood event, where the flow is exceeded on average every two years or more
FEV	Flood event volume	Total volume of flow during an individual flood event
FTTP	Flood time-to-peak	Time between the onset and peak of a flood event
FRR	Flood recession rate	The recession rate of a flood event
River flow variability		
FVa	Flow variability	Flow variability within the full flow regime
WPFVa	Wet period flow variability	Flow variability during, or in response to, periods with rainfall
DPFVa	Dry period flow variability	Flow variability during periods without rainfall

the focus of studies on North America. Consequently, one cannot necessarily transfer the results of this study to the general grouping of 'worldwide wetlands'.

(5) Conclusions are presented as stated in the original paper; no attempt is made to evaluate or uphold the conclusions that are drawn. Further work in the critical evaluation of past studies would represent a valuable contribution to the science of wetland hydrology.

(6) No attempt has been made at cross-correlation of hydrological measures within single studies. For example, if a study has concluded that a particular wetland increases evaporation, no conclusion is drawn that flow is reduced, unless that explicit statement is made by the author.

Table 5

a Gross water balance

			FP	SW/D	SW/S	GW/D	GW/S	General	Total
Mean annual flow	MAF	+	2				2		4
		-	8	1	5	1	7	1	23
		.	2	1	4		8	1	16
Mean annual actual evaporation	MAAE	+	12	1	4	1	6	1	25
		-				1	2		3
		.	1	1	1				3
Wet period flow	WPF	+	1		3		5	6	15
		-	1				2	2	5
		.	1	1		1	1		4
Wet period actual evaporation	WPAE	+						1	1
		-			1		1		2
		.							0
Dry period actual evaporation	DPAE	+	4		3		15		22
		-					1		1
		.							0
increased flow or reduced evaporation			3	0	4	1	11	6	25
reduced flow or increased evaporation			25	2	12	2	30	5	76
not increased or reduced			4	3	5	1	9	1	23

b. Groundwater recharge

			FP	SW/D	SW/S	GW/D	GW/S	General	Total
Annual groundwater recharge	AGR	+	1			1	2	1	5
		-	1		2			4	7
		.			2	1	1		4
		X	1		5	1	7	2	16
		=	8	4	2	4	6	2	26
Wet period groundwater recharge	WPGR	+		1					1
		-							0
		.							0
		X		1					1
		=	1	1		1	1		4
Dry period groundwater recharge	DPGR	+							0
		-		1	1				2
		.							0
		X		1					1
		=		1	1				2
increased recharge			1	1	0	1	2	1	6
decreased recharge			1	1	3	0	0	4	9
not increased or decreased			0	0	2	1	1	0	4
recharge does not occur			1	2	5	1	7	2	18
recharge occurs			9	6	3	5	7	2	32

c. Base flow and low flow

			FP	SW/D	SW/S	GW/D	GW/S	General	Total
Groundwater discharge site	GDS	=	2	4		3	18		27
		X		2	2		1		5
Dry period flow volume	DPFV	+	3	1	1		6	3	14
		-	5		11	1	22	8	47
		.	1		4	1	2	2	10
Dry period flow duration	DPFD	+							0
		-			1		1		2
		.							0
Dry period recession rate	DPRR	+					1	1	2
		-							0
		.							0
low flows sustained			3	1	1	0	7	4	16
low flows diminished			5	0	12	1	23	8	49
not sustained or diminished			1	0	4	1	2	2	10
groundwater discharge does not occur			0	2	2	0	1	0	5
groundwater discharge occurs			2	4	0	3	18	0	27

d. Flood response

			FP	SW/D	SW/S	GW/D	GW/S	General	Total
Floodpeak low magnitude (T>5 yrs)	FPLM	+	1		7		2	1	11
		-	12	1	7	1	10	7	38
		.	2		3		2	2	9
Floodpeak high magnitude (T<5 y	FPHM	+					1		1
		-	4	1		1	1	1	8
		.			1		2	4	7
Flood event volume	FEV	+	1		3		6	1	11
		-	4		1		3	1	9
		.							0
Flood time to peak	FTTP	+	3		2		1		6
		-	1						1
		.			1				1
Flood recession rate	FRR	+			1				1
		-			5		3		8
		.							0
floods increased or advanced or recession reduced			3	0	15	0	12	2	32
floods reduced or delayed or recession increased			23	2	11	2	15	9	62
not increase, reduced, delayed or advanced			2	0	5	0	4	6	17

e. River flow variability

			FP	SW/D	SW/S	GW/D	GW/S	General	Total
Flow variability	FVa	+			5		4	1	10
		-	6	1	2		0	1	10
		.	1		3		2		6
Wet period flow variability	WPFVa	+			1		1		2
		-							0
		.							0
Dry period flow variability	DPFVa	+							0
		-							0
		.							0
flow variability increased			0	0	6	0	5	1	12
flow variability decreased			6	1	2	0	0	1	10
not increased or decreased			1	0	3	0	2	0	6

The association between hydrological types and local terms is presented in Table 6. It is immediately evident that there is no strong linkage between hydrological categorisation as applied in this paper and the use of local or ecological wetland terms; the terms peat, bog, marsh (and several others) recur in different hydrological types. Thus, grouping by hydrological type is seen as more meaningful than grouping by local terms. For example, the term 'bog' can be found in all five hydrological types.

From a hydrological perspective, the content of the database may be perceived as limited due to its emphasis on functions rather than hydrological processes — given that the concept of functions is not well-established within the hydrological community. However, while more process information can be extracted from the set of publications, the target of this paper is the use of functional generalisations to represent wetland hydrology to the wetland management and policy arena. Clearly, there is a strong case for bringing hydrological processes and function closer together.

Geographically, the dataset is dominated by 92 studies from North America (including 23 different U.S. States and six Canadian Provinces/Territories), with additionally 33 studies from 14 countries in Europe, 27 studies from 10 countries in Africa and 17 from elsewhere (including New Zealand (2), Australia, Brazil (3), India, Indonesia and Malaysia). This distribution reflects the substantial investment in scientific enquiry in North America compared with other regions of the world and a relative dearth of accessible information relating to Asian and South American wetland hydrology.

The term 'wetland' embraces a wide variety of land types, from springs to large inland deltas. As a result, a lack of consistency in the impact of wetlands on the water cycle was anticipated. Unique conclusions concerning any specific hydrological function cannot be drawn for all wetlands. Taking flow variability as a single hydrological measure, for example, there are 28 statements with good geographical coverage, of which 10 show that variability is increased by wetlands, 11 that variability is reduced, and 6 that wetland influence is neutral. When wetlands are sub-divided into

Table 6. Wetland hydrological types and local terms

Type	*Code*	*Local terms*
Floodplain	FP	Sudd, river valley, swamp, floodplain, valley bog, marsh, cypress swamp, delta (inland), dambo, marsh, inland valley swamps and bolis, pantanal
Surface water depression	SW/D	Bog, prairie pothole, slough, kettle-hole, shallow depressions
Surface water slope	SW/S	Perched bog, peat, peat bog, pond, raised bog, blanket peat, muck, pocosin, saturated heath, palsa, aapa-mire, infilled lakes, constructed wetland
Groundwater depression	GW/D	Marsh, prairie pothole, fen, pond, bog
Groundwater slope	GW/S	Swamp, marsh, river valley, bog, dambo, fen bogs, peat bog, peat, wetland, pocosin, macrophytes, cypress domes, peat fen, pakahi, fen, mire, blanket bog, quaking fen, pond, domed bog and fen
General		Swamp, bog, marsh, 'basin storage', ponds, hydromorphic gleys, forest wetland

hydrologically similar types, greater consistency of conclusion emerges — six of seven conclusions from studies of floodplains conclude that flow variability is reduced by wetlands (including the Sudd and Okavango in Africa and Barito in Indonesia). But ambiguity still exists: amongst 19 studies of headwater wetlands (all from USA and Europe), 10 studies conclude that flow variability is increased; 5 that the wetland influence is neutral; and 4 that variability is reduced. Even apparently similar wetlands perform functions that are seemingly in opposition (e.g. peat bogs occur in each of the three categories; increasing, decreasing and not-affecting flow variability). But unanimity of function is not anticipated — there is no prior assumption that all wetlands of a particular type perform the same function. This study has not yet investigated the detailed climatology, catchment conditions and internal wetland structure, any of which can mean a particular wetland will perform differently from other wetlands that are otherwise similar.

Whether hydrological functions of wetlands are considered to be beneficial or not depends upon one's point of view. For example, ecologists may see evaporation from wetlands as an essential process supporting plant growth, whilst water resource managers may see it as a loss of a vital downstream resource. Those living in flood-prone areas downstream of wetlands that generate floods may view them negatively while those living downstream of wetlands that reduce floods may not view them in the same light. Ecologists see floods as essential elements of the river flow regime maintaining channel structure through sediment transport, and interactions between the river and its floodplain that drives nutrient exchange and breeding cycles (Junk *et al.*, 1989, Poff *et al.*, 1997).

The main conclusions of the analysis are as follows.

1. Wetlands are significant in altering the water cycle. The 169 scientific studies published during the period 1930–2002 (as traced by this paper) provide 439 statements on the hydrological significance of wetlands. Of the 439 statements, only 83 (19%) conclude the wetland influence on the water cycle to be neutral or insignificant. The vast majority conclude that wetlands either increase or decrease a particular component of the water cycle. It is this evidence that has led to the notion that wetlands perform hydrological functions. Since wetlands cover approximately 6% of the world's land area, with many linked directly to rivers and aquifers, this is an issue of importance to water management.
2. There are some significant generalisations that emerge from the published hydrological evidence. These are different from the long-standing generalisation that wetlands always reduce floods, promote groundwater recharge and regulate river flows. Most, but not all, studies (23 of 28) show that floodplain wetlands reduce or delay floods, with examples from all regions of the world. This same influence on floods is also seen, but less conclusively (30 of 66) for wetlands in the headwaters of river systems (e.g. bogs and river margins). A substantial number (27 of 66) of headwater wetlands increases flood peaks. These studies were mostly from Europe, but included work from West Africa and Southern Africa. Around half of the statements (11 of 20) for flood event volumes and 8 of 13 for wet period flows) show that headwater wetlands increase the immediate response of rivers to rainfall,

generating higher volumes of flood flow, even if the flood peak is not increased. The coverage of these studies is world-wide including Africa and South America. This function occurs because headwater wetlands tend to be saturated and convey rainfall rapidly to the river; thus they are a principal mechanism for generation of flood flows.

3. There is strong evidence that wetlands evaporate more water that other land types, such as forests, savannah grassland or arable land. Two thirds of studies (48 of 74) conclude that wetlands increase average annual evaporation or reduce average annual river flow. About 10% of studies (7) conclude the opposite; for example some woodlands in Zambia had greater evaporation than the adjacent wetlands. The remaining 25% are neutral. There is no obvious distinction amongst different wetland sub-types or geographical regions of the world.
4. Two-thirds of studies (47 of 71) conclude that wetlands reduce the flow of water in downstream rivers during dry periods. Evidence is mainly from North America and Europe, but includes floodplains in Sierra Leone and wetlands in Southern Africa. This is backed by overwhelming evidence (22 of 23 studies) that shows evaporation from wetlands to be higher than from non-wetland portions of the catchment during dry periods. There is no discernible difference for different wetland sub-types. In 20% of cases, wetlands increase river flows during the dry season.
5. Many wetlands exist because they overlie impermeable soils or rocks and there is little interaction with groundwater. The database contains 69 statements referring to groundwater recharge; 32 conclude merely that recharge takes place, and 18 conclude there is no recharge. There are similar numbers of studies that report wetlands either to recharge more (6) or less than (9) other land types. Some wetlands, such as floodplains in India and West Africa on sandy soils, recharge groundwater when flooded. Many wetlands have formed at springs and are fed by groundwater. The direction of water movement between the wetland and the ground may change in the same wetland, such as in some peatlands in Madagascar, according to hydrological conditions.
6. Conclusions have been drawn above on flow variability. The over-riding picture appears to be a reduction in flood peaks by floodplains. In some cases, such as many headwater wetlands, increasing flood flows combines with decreasing dry season flows to widen the overall range of flows.

Implications of the results for wetland research and policy formulation

This paper confirms that wetlands exert a strong influence on the hydrological cycle. It strengthens the view that management of wetlands must be an important part of integrated water resources and flood management of all river basins. Where wetlands reduce floods, recharge groundwater and increase dry season flows, wetland hydrology is working in sympathy with water resources managers and flood defence engineers. Where wetlands have high evaporation demands or generate flood-runoff, they may create or exacerbate water management problems. Whatever the hydrological functions they perform, decisions on wetland conservation will inevitably be taken in a wider context and will also depend on water scarcity and on other functions, such as human health, fisheries, navigation, recreation, cultural heritage and biodiversity.

Successful water management requires knowledge of the extent to which wetlands are performing different hydrological functions. Since it is not feasible to study every wetland in detail, rapid assessment methods are required to identify likely functions. Furthermore, a major objective of this work is to stimulate discussion on hydrological functions. It is relatively easy to add to the database, either within additional previously published work or through new research. It is harder to account for variations in functions. For it is clear that there is no simple relationship between wetland types and the hydrological functions they perform. Part of the problem steps from the lack of a simple classification of wetlands that consistently relates hydrology, vegetation, substrate type and geomorphology. It is unlikely that any sophisticated classification scheme would be able to explain the variation of function in evidence.

Various methods have been developed in a number of countries around the world to assess hydrological functions of wetlands. Some are merely classification systems that group wetlands according to botanical, geomorphological and/or water regime characteristics (e.g. Cowardine *et al.,* 1979; Brinson, 1993; Gilvear and McInnes, 1994; Wheeler, 1984). Other methods give each wetland a grade for a function, such as high medium or low (e.g. Adamus *et al.*, 1987) or produce a quantitative estimate of performance of a given function (e.g. Amman and Stone, 1991; Hruby *et al.*, 1995). Maltby *et al.* (1996) have developed a framework of functional analysis through characterisation of distinct ecosystem/landscape units (termed hydrogeomorphic units). The objective is to provide a simple and rapid procedure, but the system still needs to be operationalised. In addition, guides have been produced for extending the functional assessment to produce an economic value for the functions

(Lipton *et al.*, 1995, Barbier *et al.*, 1995). Recent work in the UK (Wheeler and Shaw, 2000) used data from over 80 wetlands in Eastern England to develop a classification and assessment system called WETMECS that combines landscape situation, water supply mechanism, hydrotopographical elements, acidity (base-richness) and fertility. The outcome of this study is that apparently similar wetlands are driven by very different hydrological processes; almost invariably, some data need to be collected at a site to identify its functional role.

Consequently, generalised and simplified statements of wetland function are discouraged because they demonstrably have little practical value. As a minimum, this paper encourages the future representation of diversity and complexity amongst wetlands and the portrayal of diverse hydrological functions.

Hydrologists must be more imaginative and proactive in contributing scientific knowledge to underpin policy formulation and management decisions. For the hydrological community, a new challenge is set for wetland policy.

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Annex 1

GLOBAL REVIEW OF WETLAND WATER QUANTITY FUNCTIONS

Author	*Country (state, province)*	*Wetland type*	*Local term*	*Basis of inference*	*Category of study*	*Summary of functional statement*	*Function summary*
Hurst (1933)	Sudan	FP	Sudd	In-Out	LTH	FVa: swamp discharge varies very little; fluctuations are rapidly damped out MAAE: 14 milliards of flow is lost in the swamps (p.731-2)	FVa: - MAAE: +
Vecchioli *et al*. (1962)	New Jersey, USA	GW/S	Swamp, marsh	In-out	LTH	DPFV: baseflow is reduced to 75% of the input ... DPAE: ... by high summer evapotranspiration MAF : swamplands have little effect on the total flow FPLM: the swamp decreases the downstream floods FEV: seasonal runoff is greater than that of the upland (p.699-700)	DPFV: - DPAE: + MAF: . FPLM: - FEV: +
Riggs (1964)	N. Carolina, Tennessee, USA	General	Swamp	Paired	LTH	DPRR: comparison of a flat recession for the swampy Haw, with a steep recession of the non-wetland New River (p.359).	DPRR: +
Meyboom (1964)	Saskatchewan, Canada	GW/S	River valley	$Comp_V$	SEH	DPFV: 70% of flow depletion can be accounted for by phraetophytic vegetation (p.254)	DPFV: -
		FP	River valley	$Comp_V$	SEH	DPFV: phreatophytes in the valley diminished flow by at least 20% (p.257).	DPFV: -
		FP	River valley	$Comp_V$	SEH	DPFV: phreatophytes depleted 100% of river flow (p.259)	DPFV: -
Meyboom (1966)	Saskatchewan, Canada	GW/D	Prairie pothole	$Comp_{GW}$	$Comp_{gw}$	AGR: "Groundwater was recharged during the period of study" (p.60)	AGR+
Miller (1965)	New Jersey, USA	GW/S	Swamp, marsh	In-out	WB	DPFV/DPAE: summer evapotranspiration causes a significant reduction in baseflow GDS: the swamp is an area of discharge for the regional groundwater body (p. B179)	DPFV: - DPAE: + GDS: =
Ackroyd *et al.* (1967)	Minnesota, USA	General	Swamp, bog, marsh	Multiple	LTH	DPFV: basins having lake or wetland areas in excess of 5% have more than twice as much annual groundwater runoff. (p.27)	DPFV: +
Bay (1967)	Minnesota, USA	SW/S	Perched bog	$Comp_{GW}$	$Comp_{GW}$	GDS: the water table reacts quite independently from the regional groundwater system (p. 309)	GDS: X
		GW/S	Bog	$Comp_{GW}$	$Comp_{GW}$	GDS: groundwater from surrounding mineral soil recharges the bog (p.309)	GDS: =
Burke (1968)	Ireland	SW/S	Peat	Drained	WB	MAF: outflow is the same from drained and undrained area DPFV: flow eventually becomes zero from both areas FPLM: much higher peaks occur for the undrained area FTTP: the undrained area flows sooner than the drained area FRR: after flood peaks, the drained area is still discharging water at a faster rate WPFVa: sustained flows are more uniform in the drained area (p.814-6)	MAF: . DPFV: . FPLM: + FTTP: + FRR: + WPFVa: +

Romanov (1968)	Former USSR	SW/D	Bogs	Same	WB	MAAE/MAF: bog evaporation and runoff approaches that of unbogged areas FVa: drainage of highmoor bogs causes the redistribution to become more marked. (p.232-3)	MAAE: . MAF: . FVa: -
Shjeflo (1968)	N. Dakota, USA	SW/D	Prairie pothole	$Comp_{GW}$	WB	WPGR: it was assumed that no seepage took place during the winter months when the potholes were frozen (p.B48)	WPGR: X
Williams (1968)	Illinois, USA	GW/D	Marsh	$Comp_{GW}$	$Comp_{GW}$	GDS/AGR: some marshes behave as groundwater sinks, others as a groundwater mound (p.782)	GDS: = AGR: =
Bay (1969)	Minnesota, USA	SW/S	Peat bog	Same	LTH	DPFD: storage was not available to sustain summer flow FVa: bogs were not effective as streamflow regulators FPLM/ FRR: low peak flows and long-drawn out recessions suggest that the bogs do store short-term runoff (p.101)	DPFD: - FVa: . FPLM: - FRR: -
Freeze (1969)	Saskatchewan, Canada	SW/D	Slough	$Comp_{GW}$	Chem	DPGR: among 76 sloughs 27 are classified as 'Fast Recharge', 10 as 'Slow Recharge' and 39 do not recharge GDS: 14 are classified as 'Fast discharging sloughs', 10 as 'Slow Discharging sloughs', 50 do not discharge. (p. 12-14)	DPGR: = DPGR: X GDS: = GDS: X
Campbell & Drecher (1970) in Novitski (1985)	Wisconsin, USA	General	Basin storage	Multiple	LTH	WPF/AGR/ DPFV: in basins with large lake and wetland area, more water runs off in spring and only a small amount recharges the aquifer; thus base flow is reduced in summer, fall and winter (Novitski, p. 147)	WPF: + AGR: - DPFV: -
Darmer (1970) in Novitski (1985)	New York, USA	General	Lakes and ponds	Multiple	LTH	FPHM: basin storage is statistically insignificant in explaining the variability of flood peaks (T = 20 yrs) AGR/DPFV: large percentage of storage in basins results in reduced recharge and consequently reduced baseflow (Novitski, p. 145-8)	FPHM: . AGR: - DPFV: -
Forest & Walker (1970) in Novitski (1985)	Delaware, Maryland, USA	General	Basin storage	Multiple	LTH	FPHM: basin storage is statistically insignificant in explaining the variability of flood peaks (T = 5-100 yrs) AGR/WPF/DPFV: spring runoff is greater and recharge to groundwater (and baseflows) lower in basins with a larger percentage of lake and wetland area (Novitski, p.145-9)	FPHM: . AGR: - WPF: + DPFV: -
Nuckles (1970) in Novitski (1985)	Virginia, USA	General	Basin storage	Multiple	LTH	FPHM: basin storage is statistically insignificant in explaining the variability of flood peaks (T = 5-100 yrs) WPF/DPFV: annual minimum series are lower for basins with large percentages of lakes and wetlands (Novitski, p.149)	FPHM: . WPF: + DPFV: -
Wharton (1970)	Georgia, USA	FP	Swamp	Paired	LTH	FPLM: a comparison of Alcovy (swamp) and Yellow hydrographs suggests a damping influence FTTP: peaks of the Alcovy lag 24 hours behind the Yellow FVa: Alcovy flow durtion curves are smooth and many minor fluctuations shown for the Yellow are missing. It is likely that the Alcovy (alluvial) aquifer beneath the floodplain does strongly influence the variability of base flow DPFV: although the Yellow drains an area 36% larger, its low flows are close to those of the Alcovy, suggesting some possible influence of the swamp on base flow (p.15-18).	FPLM: - FTTP: - FVa: . DPFV: +

Conger (1971) in Novitski (1985)	Wisconsin, USA	General	Basin storage	Multiple	LTH	FPHM: basin storage is significant in explaining variability in flood peaks (T = 2-100 yrs); the higher the storage term, the lower the flood peaks. (p.144-5)	FPHM: -
Kloet (1971) in Bardecki (1987)	N. Dakota, USA & Manitoba, Canada	General	General wetland	Drained	LTH	FPLM: peak flow is increased due to drainage in a comparative study of a drained and undrained basin (Bardecki, p.126);	FPLM: -
Millar (1971)	Canada	GW/S	Prairie pothole	$Comp_{GW}$ $Comp_{E}$	WB	AGR: "Shoreline related water loss accounts, on average, for 60% or more of total water loss in sloughs less than 1.0 acres in size and not more than 30-35% in sloughs larger than 1 acre" (p.259) DPAE: "Reduction in evaporation loss (is due to) the sheltering effect of topography and marginal and emergent vegetation" (p279)	AGR+ DPAE: -
Eisenlohr (1972)	N. Dakota, USA	GW/D	Prairie pothole	$Comp_{GW}$	$Comp_{GW}$	GDS: ponds in prairie potholes, in effect, are "outcrops" of the water table (p.A82)	GDS: =
Hall et al. (1972)	New Hampshire, USA	SW/S	Pond	$Comp_{V}$	$Comp_{V}$	DPFV: there is no evidence of the wetland sustaining baseflow (p.41)	DPFV: .
McComas *et al.* (1972)	Illinois, USA	GW/S	Bog	In-out	WB	DPFV: no groundwater left the basin as baseflow FEV: materials are saturated in the spring and little further retention takes place. (p.17)	DPFV: - FEV: +
Stewart & Kantrud (1972)	N.Dakota, USA	SW/D	Prairie pothole	$Comp_{GW}$	Chem	AGR: seepage accounted for some water loss in ponds at higher elevations on glacial till. (p.D4-D5)	AGR: =
		GW/S	Prairie pothole	$Comp_{GW}$	Chem	GDS: Ponds at lower elevations, on outwash, were subject to greater seepage inflow. (pD4 -D5)	GDS: =
Balek & Perry (1973)	Zambia	GW/S	Dambo	Same	CCM	MAF: total runoff is independent of the size of the dambos WPF: from a higher percentage of dambo area, a higher surface runoff volume occurs FRR: duration of surface runoff as compared with a non-swampy area is delayed by dambo resistance MAAE: evapotranspiration by woodland is three times higher than that from dambos DPFD: base flow from the dambo ceases earlier than from the transitive region DPRR: recessions are steeper from a catchment containing 10% dambo compared with 5% dambo (239-248)	MAF: . WPF: + FRR: - MAAE: - DPFD: - DPRR: +
Wilson & Wiser (1974)	S. Carolina, USA	FP	Floodplain	In-out	LTH	DPFV/DPAE: not only does the lower (floodplain) zone fail to contribute water but through it some of the potential baseflow is lost to evapotranspiration (p.274)	DPFV: - DPAE: +
Bavina (1975)	European USSR	SW/S	Raised bogs	Paired	WB	MAF: runoff from the swamp and from the (non-swamp) river basins was the same (p.301)	MAF: .
		FP	Valley bogs	Paired	WB	MAF : runoff from the swamp is in general agreement with runoff from the swampy catchment (p.302)	MAF: .

Bulavko & Drozd (1975)	USSR	General	Peat	Drained	LTH	MAF/MAAE: initially after drainage annual runoff is increased due to a decrease in evapotranspiration WPF: spring flows either increase or decrease DPFV: minimum and summer low flows increase considerably FVa: the proportion of the groundwater contribution to flow increases, improving the distribution of river runoff (p.466)	MAF: - MAAE: + WPF: + WPF: - DPFV: - FVa: +
Burke (1975)	Ireland	SW/S	Blanket peat	Drained	WB	MAF/FVa/FEV: the drained area runoff was 60% greater than the undrained area. Flow was much more uniform and did not show the sharp peaks evident in the undrained area AGR: some seepage may occur, albeit small, but both peat and the subsoil have extremely low permeability FPLM/DPFV: after drainage, floods will be reduced in frequency and amount and summer flow of streams will be increased in the short-term (p.176)	MAF: - FVa: - FEV: - AGR: . FPLM: + DPFV: -
Eggelsmann (1975)	Germany	SW/S	Peat	Same	WB	MAAE/MAF: there is higher evaporation from peat and reduction of runoff with respect to mineral soils FVa: there is no causal relations between the steady runoff and the water storage of peat (p.359)	MAAE: + MAF: - FVa: .
Eisenlohr (1975)	N. Dakota, USA	GW/D	Prairie Pothole	$Comp_{GW}$	$Comp_{GW}$	AGR: although there is evidence that a very small portion of seepage moves vertically downward, most of the seepage outflow moves laterally (p.309)	AGR: .
Glazacheva (1975)	Latvia	General	Marsh	Drained	LTH	FVa/FPLM/DPFV: river flow variability increased following drainage as the maximum discharges increased and the minimum decreased (p.514)	FVa: - FPLM: - DPFV: +
Hommik & Madissoon (1975)	Estonia	GW/S	Fen bogs	Drained	WB	MAF: annual runoff from drained fen bogs increases by 92mm (p.489)	MAF: -
Kiselev (1975)	Byelarus	GW/S	Swamp	$Comp_{GW}$	$Comp_{GW}$	AGR/GDS: swamps may be supplied by groundwater and may also serve as sources of groundwater recharge (p.38-40)	AGR: = GDS: =
Klueva (1975)	Byelorussia	SW/S	Marsh	Drained	LTH	DPFV: the minimum discharge increased by 30-150% FPLM: maximum discharges decreased by 17-30% on 7 basins; in other basins no significant change occurred FTTP : no significant changes were observed in the timing of the snowmelt flood, or in the date of the peak FVa: 6 basins were characterised by decrease of spring flow of 10 to 30%; summer and autumn flow increased 20 to 60% MAF: MAF of 9 basins increased by 10 to 20%. On the other 7 basins there was no significant change (p.424-6).	DPFV: - FPLM: + FPLM: . FTTP: . FVa: + MAF: - MAF: .
Moklyak *et al.* (1975)	Ukraine	FP	Marsh	Drained	LTH	MAF: runoff tends to decrease after drainage WPF: decrease in spring flows is generally found but cases are encountered where the flow is unchanged or tends to increase FPLM : drainage does not always affect the maximum discharge, although it may either decrease or increase (p.442)	MAF: + WPF: + WPF: . WPF: - FPLM: + FPLM: . FPLM: -
Mikulski & Lesniak (1975)	N.E. Poland	GW/S	Peat bog	Drained	WB	MAAE: evaporation decreased by about 15% as compared with the pre-reclamation period MAF/WPF/DPFV: results show a 20% increase in runoff, as compared to the pre-reclamation period... there were increases in the runoff, in summer and autumn (p.59)	MAAE: + MAF: - WPF: - DPFV: -

Mustonen & Seuna (1975)	Finland	SW/S	Peat	Drained	LTH	MAAE/MAF: decrease in evapotranspiration led to an increase in total runoff FPLM: an acceleration of flow caused by the drainage network led to an increase in maximum runoff DPFV: the minimum runoff for both winter and summer increased markedly (p.523)	MAAE: + MAF: - FPLM: - DPFV: -
NERC (1975)	UK	FP	Floodplain	In-out	SEH	FPLM/FPHM: the most important change induced by a large floodplain on the shape of a flood hydrograph is the attenuation of the peak discharge (p.9)	FPLM: - FPHM: -
Smith (1975)	Florida, USA	FP	Cypress swamp	Same	$Comp_{GW}$	AGR: clays between the water table and the Floridan aquifer allow virtually no vertical movement MAAE: vegetation is acting as a pump, removing water from the water table via transpiration (p.128-135)	AGR: X MAAE: +
Verry & Boelter (1975)	Minnesota, USA	GW/S	Lake-filled bog	Same	LTH, SEH	FVa: the groundwater bog has no regulating effect FPLM: the bog does reduce storm flow peaks FPHM: maximum peaks are independent of the bog FRR: the bog delays the release of storm flow (p.472)	FVa: . FPLM: - FPHM: . FRR: -
		SW/S	Lake-filled bog	Same	LTH, SEH	FVa: the perched bog has no regulating effect FPLM: the bog does reduce individual storm peaks FPHM: maximum peaks are independent of the bog FRR: the bog delays the release of storm flow (p.472)	FVa: . FPLM: - FPHM: . FRR: -
Zivert *et al.* (1975)	USSR	GW/S	Fen bog	Same	WB	MAF/WPVa: in fen bogs drainage flow is 20 to 40% greater than mineral soils. The hydrograph of flood discharge is more uniform in peat than in mineral soils (p.121)	MAF: + WPVa: -
Heikuranen (1976)	Finland	SW/S	Peat	Drained	WB	WPF: peak flow caused was considerably lower on the drained peatland FTTP: the flood from the drained peatland began earlier and lasted longer FPLM: peak flow of the former remained lower DPFV: runoff from the drained peatland during the dry summer was greater FRR: flood from the drained peat began earlier and lasted longer (p.84-5)	WPF: + FTTP: + FPLM: - DPFV: - FRR: -
Sander (1976)	Minnesota, USA	GW/S	Bog	In-out	WB /CCM	FVa: the bog's chief role is to superimpose a significant seasonal fluctuation on discharge WPF: the bog releases excess water during wet periods DPFV/DPAE: the bog depletes available supplies during dry periods through evapotranspiration GDS: the wetland receives water from groundwater (p.35)	FVa: + WPF: + DPFV: - DPAE: + GDS: =
Wilson & Dincer (1976)	Botswana	FP	Delta	In-out	WB	MAAE/MAF: outflow in the Boteti amounts to only 2% of inflow due to the evapotranspiration losses (p.36).	MAAE: + MAF: -
Balek (1977)	Zambia	GW/S	Dambo	Same	WB/ CCM	FRR: the duration of the surface runoff is prolonged until early June (p.159)	FRR: -
Boelter & Verry (1977)	Northern Lake States, USA	SW/S	Perched peat bog	$Comp_{GW}$	WB	DPFV/DPAE/AGR: late spring, summer and early fall evapotranspiration is at the expense of flow and deep seepage; peatland does not sustain streamflow during dry summer months by slowly releasing stored water FRR: stormflows are modified by peatland. Storm hydrographs have long-drawn out recession curves FPLM: peatland does reduce the peak rates of flow FVa: neither bogs nor fens maintain an even distribution of streamflow (p.14-18)	DPFV: - DPAE: + AGR: - FRR: - FPLM: - FVa: +

		GW/S	Groundwater peat fen	$Comp_{GW}$	WB	FVa/WPF/DPFV/DPAE: instead of regulating flow, the fen may do the opposite by releasing excess water more quickly than mineral aquifers during periods of high precipitation and losing more water by evapotranspiration during dry periods (p. 15-16)	FVa: + WPF: + DPFV: - DPAE: +
Flippo (1977) in Novitski (1985)	Pennsylvania, USA	General	Basin storage	Multiple	LTH	FPHM: basin storage is statistically insignificant in explaining the variability of flood peaks (T = 5-100 yrs) (p.145)	FPHM: .
Hickok *et al.* (1977)	Minnesota, USA	GW/S	Wetland	Same	WB	AGR/GDS: the wetland is a point of discharge for the local glacial till. Groundwater losses are considered zero DPFV: the wetland reduced minimum flow to less than the estimated base flow (p.46)	AGR: X GDS: = DPFV: -
Littlejohn (1977)	Florida, USA	FP	Cypress swamp	Drained	CCM	FVa: retention of cypress swamps contribute to greater stability of water regimes (p.472)	FVa: -
Mitsch *et al.* (1977)	Illinois, USA	FP	Forest swamp	Same	WB	FEV: water retained by the swamp is 7.8% of an individual event. No effect was seen on any other storm occurrences DPFV: flow maintenance can be very significant (p.77-8,90)	FEV: - FEV: . DPFV: +
O'Brien (1977)	Massachusetts, USA	GW/S	Peat	Paired, Same	WB, LTH	WPAE: spring evapotranspiration is depressed relative to non-wetland WPF: the wetland was responsible for high spring flows DPAE: fall rates are high relative to non-wetland areas DPFV: baseflow during the low flow period was greatly depressed GDS: the wetland receives water from the regional groundwater body (p.336-338)	WPAE: - WPF: + DPAE: + DPFV: - GDS: =
		SW/S	Muck wetland	Paired, same	WB, LTH	WPAE: spring evapotranspiration is depressed relative to non-wetland WPF: the wetland was responsible for high spring flows DPAE: fall rates are high relative to non-wetland areas DPFV: baseflow was greatly depressed DPGR: during summer the swamp recharges groundwater (p.336-8)	WPAE: - WPF: + DPAE: + DPFV: - DPGR: =
Winner & Simmons (1977)	N. Carolina, USA	FP	Floodplain swamp	Drained	LTH	FPLM/DPFV/MAF: higher flows (> 5 exceedance-percentile) increase; low flows increase. Total runoff would not change (p.53)	FPLM: - DPFV: - MAF: .
Novitski (1978)	Wisconsin, USA	General	Wetland and lake	Multiple	LTH	FPLM: flows may be 80% lower in basins with much wetland and lake WPF: more spring runoff occurs in basins with much wetland and lake AGR/DPFV: less groundwater recharge (and baseflow) occurs in basins with much lake and wetland (p.384-6)	FPLM: - WPF: + AGR: - DPFV: -
Verry & Boelter (1978)	Minnesota, USA	GW/S	Fen	Same	WB	AGR: the GW/S fen does not discharge through the peat (p.398)	AGR: x
		SW/S	Peat	Same	WB	FVa: peats do not regulate flow from one season to another FPLM: peat does reduce the peak flow DPFV/DPGR: peat summer evapotranspiration is at the expense of streamflow or recharge (p.398)	FVa: - FPLM: - DPFV: - DPGR: -
McKay *et al.* (1979)	Illinois, USA	GW/S	Swamp	$Comp_{GW}$	WB	GDS: the volume of (ground-) water annually entering the swamp by discharge from the bedrock is quite large (p. 31).	GDS: =

Drayton *et al.* (1980)	Malawi	FP	Dambo	Multiple	LTH	FPHM: dambo provides a lot of floodplain storage DPFV: dambo catchments are not significantly distinguishable from unaffected neighbours for Q75 MAAE/MAF: presence of dambo increases evaporation with a corresponding decrease in average annual yield (p.58)	FPHM: - DPFV: . MAAE: + MAF: -
Hemond (1980)	Massachusetts, USA	SW/D	Kettle hole	In-out	WB	GDS: the bog is characterised by an absence of recharge (p.522)	GDS: X
Hill & Kidd (1980)	Malawi	GW/S	Dambo	Multiple	LTH	MAAE/MAF: average annual runoff volume is reduced by 6.4mm for every 1% of dambo (p.16)	MAAE: + MAF: -
O'Brien (1980)	Massachusetts, USA	GW/S	Wetland	$Comp_{GW}$	LTH	WPF: groundwater was the major component of all flood peaks (rather than originating from the wetlands) (p.359)	WPF: .
Bedinger (1981)	Mississippi, USA	FP	Floodplain	$Comp_{GW}$	LTH	FPLM: floodplains ameliorate downstream flooding AGR: significant recharge occurs on floodplains (p.168,173)	FPLM: - AGR: =
Brun *et al.* (1981)	N. Dakota, USA	GW/D	Sloughs	Drained	TS	MAF/FPHM/DPFV: approximately 50% of the increase in flow, 36% of the increase in maximum flow, and 70% of the increase in spring flow is due to increased drainage (p.13)	MAF: - FPHM: - DPFV: -
Daniel (1981)	N. Carolina, USA	GW/S	Pocosin	Drained	WB	FPLM: hydrographs from the Albemarle Canal show five floods while the wetland Van Swamp show none DPFV/DPAE: from raised wetlands there is usually little discharge after June because of evapotranspiration MAF: runoff from the two catchments is nearly equal (p.90-3)	FPLM: - DPFV: - DPAE: + MAF: .
Gilliam & Skaggs (1981)	N. Carolina USA	GW/S	Pocosin	Drained	WB	FPLM/FTTP: peaks are higher and earlier on developed sites MAF: there was little difference in total flow (p.115)	FPLM: - FTTP: + MAF: .
Newson (1981)	Wales, UK	GW/S	Peat	Same	SEH	DPFV: very low yields prevailed, excepting two headwater areas characterised by periglacial deposits and peat (p.69).	DPFV: +
Nortcliff & Thornes (1981)	Brazil	FP	Floodplain	$Comp_{WC}$	WB	FEV: the dominant and rapid hydrograph response comes essentially from saturation overland flow on the floodplain (p.54)	FEV: +
Sellars (1981)	Nigeria	FP	Floodplain	$Comp_{ET}$	CCM	MAF/DPFV/AGR: losses in the Upper Yobe are 70% of MAF. Storage causes flooding to continue into the dry season. 10% of losses contribute to regional groundwater (p. 267)	MAF: - DPFV: + AGR: =
Novitski (1982)	Wisconsin, USA	SW/D	SW/D wetland	Same	WB	A surface-water depression wetland has ... FPLM: ... an effect in reducing flood peaks DPFV: ... some effect on increasing base flows WPF: ... no effect on increasing spring time runoff MAAE: ... some effect in increasing ET (p19-.20)	FPLM: - DPFV: + WPF: . MAAE: +
		SW/S	SW/S wetland	Same	WB	A surface-water slope wetland has ... FPLM: ... an effect in reducing flood peaks DPFV: ... some effect on increasing base flows WPF: ... increases spring time runoff MAAE: ... no effect on ET (p.19-20)	FPLM: - DPFV: + WPF: + MAAE: .
		GW/D	GW/D wetland	Same	WB	A ground-water depression wetland has ... FPLM: ... an effect in reducing flood peaks DPFV: ... no effect on increasing base flows WPF: ... no effect on increasing spring time runoff MAAE: ... an effect in increasing ET AGR: some recharge occurs (p.19-20)	FPLM: - DPFV: . WPF: . MAAE: + AGR: =

		GW/S	GW/S wetland	Same	WB	A groundwater slope wetland has ... FPLM: an effect in reducing flood peaks DPFV: no effect on increasing base flows WPF: an effect in increasing spring time runoff MAAE: some effect in increasing ET (p.19-20)	FPLM: - DPFV: . WPF: + MAAE: +
		General	Wetland and lake	Multiple	LTH	FPLM: flood peaks are 80% lower in a basin with 40% lake and wetland area than in a basin with no lake or area (p.16)	FPLM: -
Verry & Timmons (1982)	Minnesota, USA	SW/S	Peat	Same	WB	MAF: peat converts 36% of its precipitation to water yield, or nearly the same as the upland FEV: during high water table periods, the bog can transmit flow much quicker than the mineral soil AGR: because hydraulic conductivities of well-decomposed peat and glacial till are similar, seepage rates over long periods probably are similar (p.1461)	MAF: . FEV: + AGR: .
Howard-Williams (1983)	New Zealand	GW/S	Macrophytes	$Comp_{ET}$	LTH	DPAE: distinct diurnal rhythms in hydrographs were caused by evaporative losses during the day, which could not be detected when the macrophyte growth was minimal (p.57)	DPAE: +
Ludden *et al.* (1983)	N. Dakota, USA	SW/D	Shallow depressions	Multiple	LTH	MAF/FPHM: the depressions store 72% of 2-yr return period flow and 41% of 100-year return period flow (p.45)	MAF: - FPHM: -
Seyhan *et al.* (1983)	Natal, South Africa	FP	Marsh	Same	LTH	DPAE: recession hydrographs exhibit diurnal fluctuations with greater evapotranspirational losses in the riparian zone during the day (p. 88)	DPAE: +
Siegel (1983)	Minnesota, USA	GW/S	Raised bogs Fens	$Comp_{GW}$	CCM	AGR: recharge zones in the peats are the raised bogs, and the discharge zones are the adjacent fens. Precipitation on the fens does not enter the groundwater system (p. 918)	AGR: = GDS: = AGR: X
Smith-Carrington (1983)	Malawi	GW/S	Dambo	Same	WB	MAAE: actual annual evaporation losses from dambos is 640mm compared with 692mm from shallow interfluve and 760mm from wooded interfluve FEV: hydrographs show more flashy responses because there is less dambo area for temporary retention of water. DPFV/DPAE: high dambo evapotranspiration results in a decrease in flow rate and cessation of river flow (p.36).	MAAE: - FEV: - DPFV: - DPAE: +
Heimburg (1984)	Florida, USA	GW/S	Cypress domes	$Comp_{GW}$	WB	AGR: usually Sewage Dome 2 recharges the groundwater. At Austin Cary there is little deep percolation as the underlying aquifer is artesian (p. 80).	AGR: = AGR: X
Keough & Pippen (1984)	S.W. Michigan, USA	GW/D	Peat bog	In-out	Chem	WPGR: bog waters are moving locally into groundwater DPFV: wetlands retain rain and incoming runoff and groundwater until it evaporates or percolates (p.839)	WPGR: = AGR: =
Sharma (1984)	Zambia	FP	Floodplain	Same	$Comp_{ET}$	MAAE: evaporation from flooded areas on the Flats is considerably higher than from non-flooded areas. (p.12-21)	MAAE: +
Dubreuil (1985)	W.Africa	General	Hydromorphic/ gley soil	Same	Comp	FPLM: minimum rainfall required to produce runoff from hydromorphic/gley soils is lower than from ferrallitic soils FEV: on freely drained forest soils, no runoff occurs under rainfall of 120mm hr^{-1}, while runoff attained 80% of input under rainfall of 30mm h^{-1} on hydromorphic soils WPAE/WPF: losses are far greater during severe floods where there are floodplains. In Mauritania, this represents almost 30% of the total flood volume AGR: when a stream disappears into its floodplain, the alluvial water table may be replenished (p.244-257)	FPLM: + FEV: + WPAE: + WPF: - AGR: +

Millington (1985)	Sierra Leone	FP	Inland valley swamps and bolis	Same	LTH	DPFV: during the dry season, swamps retain surface water which is lost by evaporation and seepage (p.19)	DPFV: - AGR: = DPAE: +
Novitski (1985)	Northern and Eastern States, USA	General	Wetland and lake	Multiple	LTH	In basins with large percentages of lakes and wetlands... FPLM : flood peaks are less WPF: spring runoff is greater DPFV: baseflow is less (p.151)	FPLM: - WPF: + DPFV: -
Baden & Eggelsmann (1986)	Germany	SW/S	Raised bog	Drained	WB	FVa: run-off of the predrained bog was more extreme FPLM/DPFV: run-off in downstream areas are such that the risk of highwater and dryness becomes smaller (p.206-8)	FVa: + FPLM: + DPFV: -
Gurnell & Gregory (1986)	England, UK	SW/S	Saturated heath	Same	LTH	FPLM: storm runoff volume can be related to the area of the catchment that is saturated or has a near-surface water table prior to a storm (p.94)	FPLM: +
Ogawa & Male (1986)	Massachusetts, USA	FP	Wetland	With-out	CCM	FPLM: the worth of an upstream wetland for flood mitigation is negligible. Downstream main-stem wetlands were more effective in reducing downstream flooding (p.114)	FPLM: . FPLM: -
Roulet & Woo (1986)	NW Territories, Canada	GW/S	Peat	$Comp_{WC}$	WB	DPFV/DPAE/FVa: post-spring water loss is mainly due to evaporation and not lateral runoff. Wetlands do not play an important role in streamflow regulation (p.89)	DPFV: - DPAE: + FVa: .
Wilcox *et al.* (1986)	Indiana, USA	GW/S	Peat fen	$Comp_{GW}$	$Comp_{GW}$	AGR: a water table in the peat mound causes a pattern of shallow groundwater flow away from the peat mound GDS: seepage through marl into peat is deduced (p.1111-3)	AGR: = GDS: =
Bardecki (1987)	S.W. Ontario, Canada	General	General	Drained	LTH	MAF/ FPLM/DPFV: neither strong evidence nor clear suggestions of any change in flow attributable to drainage was found (p.127)	MAF: . FPLM: . DPFV: .
Doyle (1987)	Massachusetts, USA	FP	Floodplain	Paired	LTH	FPHM: maximum floods in the Charles are extremely low compared to the adjacent low wetland Blackstone river (p.111)	FPHM: -
Ford & Bedford (1987)	Alaska, USA	General	General wetland	In-out	WB	AGR: the contribution of Alaskan wetlands to groundwater is probably negligible FPLM: during snowmelt, wetland soils do not contribute significantly to flood storage (p.209).	AGR: X FPLM: .
Jackson (1987)	South Island, New Zealand	GW/S	Pakihi wetland	Drained	WB	FEV: natural undrained wetlands are highly responsive to rainfall. Over 70% of total annual runoff is quickflow DPFV: low flows increased after vegetation was removed, but decreased after draining. FPMH: increased frequency of large peak flows is probably the most important impact of drainage works (p.471-3)	FEV: + DPFV: - DPFV: + FPHM: -
Robertson (1987)	Alaska, USA	General	General	Same	LTH	DPFV: wetlands contribute little to the mid-summer budget of tundra streams (p.267)	DPFV: .
Woo & Heron (1987)	N. Ontario, Canada	GW/S	Bogs and fens	$Comp_{WC}$	WB	GDS: meltwater from open bogs and fens is supplied by the local snow cover and from adjacent forested areas. Most of the runoff from the bog occurred as groundwater flow (p.303-4)	GDS: =

Brandesten (1988)	S.C. Sweden	GW/S	Mire	Multiple	LTH	DPFV: the principal difference between raised bogs and till is groundwater levels in the bogs are always sufficiently high to provide the streams from these areas with runoff (p.90)	DPFV: +
Konyha *et al.* (1988)	North Carolina, USA	GW/S	Peat	Drained	CCM	MAF/FPLM: peat mining alone increases the annual runoff and peak outflow rates (p.490)	MAF: - FPLM: -
Kovrigo & Yatsukhno (1988)	Byelorussia	SW/S	Bog	Drained	WB	MAAE: evaporation decreases 7-10% following drainage reclamation (p.24)	MAAE: +
Kowalik *et al*. (1988)	Poland	GW/S	Peat	Comp GW	Comp GW	GDS: upward seepage is about 30% of rainfall (p.178)	GDS: =
Lundin (1988)	Sweden	GW/S	Peat	Drained	WB	MAF: drainage changed MAF insignificantly DPFV: low discharges generally increased (p.204)	MAF: . DPFV: -
Moskvin (1988)	West Siberia	SW/S	Palsa bogs	Same	LTH	DPFV: flow ceases completely in some weeks or months of the warm period due to low storage capacity AGR: there is a lack of losses by percolation into deep aquifers through saturated frozen peat layers (p.20-1)	DPFV: - AGR: X
Nisula & Kuittinen (1988)	Finnish Lappland	SW/S	Aapa-mire	Same	WB	FEV: maximum runoff was caused by rapid runoff of the water from the mire (p.81)	FEV: +
Panu (1988)	Newfoundland, Canada	GW/S	Peat	Drained	LTH	FPLM: peak flows are increased by two to five folds DPFV: flow regime in the disturbed sub-basin experienced substantial changes such as decrease in low flows (p.295-6)	FPLM: - DPFV: +
Serban *et al.* (1988)	Romania	GW/S	Peat	Paired	LTH	FEV: runoff in the peat basin is 30-35% lower than in the control (p.93-94)	FEV: -
Sharma (1988)	Africa, Zambia	GW/S	Dambos	Same	WB	MAAE: a ratio of ET/PET (Penman) equal to 1.5 is not surprising for tropical wetlands (p.38-39)	MAAE: +
		FP	Swamps	Same	WB	MAF: because of the swamps, the mean annual runoff is reduced to 5600 x 10^6 m^3 (p.38-9)	MAF: -
Shiklimanov & Novikov (1988)	Russia	GW/S	Swamp	Drained	LTH	MAF: drainage mainly increases MAF in the first years. There are some cases when MAF is reduced FPLM: high spring maxima tend to fall DPFV: minimum and summer runoff from swamps after drainage tends to increase FVa: drainage is manifested as more uniform and even flow distribution over seasons (p.69-71)	MAF: - MAF: + FPLM: + DPFV: - FVa: +
Siegel (1988)	Alaska, USA	GW/S	Blanket bog	Same	CCM	AGR/GDS/DPFV: wetland recharge and discharge are very small. Groundwater discharge from wetlands is too small to measure (p.427)	AGR: X GDS: X DPFV: -
Verry (1988)	Minnesota, USA	GW/S	Mire	Same	SEH	FPHM: during large storms, peat looks like a reservoir - overland flow from the mineral soil was not observed (p.55)	FPHM: +
Brooks & Kreft (1989)	Minnesota, USA	GW/S	Fen peat and bog	Drained	CCM	FEV: runoff is greater for mined peatlands than unmined DPFV: streamflow is generally reduced during summer months because of high evapotranspiration MAF: peat extraction in both bogs and fens appears to increase water yield over the short term (p.114-5)	FEV: - DPFV: - MAF: -

Koerselman (1989)	Netherlands	GW/S	Quaking fen	Same	WB	GDS: the fen is a focus for groundwater discharge (p.31)	GDS: =
Stewart (1989)	Zimbabwe	GW/S	Dambo	Same	$Comp_{ET}$	DPAE: the mean value of evaporation over all dambo regions over the 200 km^2 was estimated to be 3.5mm d^{-1} and 3.2mm d^1 for the area outside the dambos (p.48-59)	DPAE: +
Sundeen *et al.* (1989)	Colorado, USA	SW/S	Infilled lakes	In-out	LTH	FPLM: wetlands do not have a substantial affect on the magnitude of flood peaks. The wetlands may have a lesser ability to attenuate flood peaks than would upland areas. AGR: wetlands have no significant role in groundwater recharge. (p.412)	FPLM: . FPLM: + AGR: X
Sutcliffe & Parks (1989)	Africa	FP	Floodplain	Multiple	CCM	MAAE: losses in the Sudd and in the Niger are over half the annual inflow, in the lower Senegal are insignificant, and in the Okavango are a very high proportion of the inflows FVa: Okavango and Sudd outflows are even less variable after damping (p.54-5).	MAAE: + MAAE: + MAAE: + MAAE: . FVa: - FVa: -
Brown (1990)	North America, USA	General	Forest wetland	$Comp_{GW}$	WB	AGR: the bog and pocosin wetlands have virtually no recharge, the cypress dome experiences losses through infiltration or seepage (p.172-173)	AGR: X AGR: =
Gehrels & Mulamoottil (1990)	S. Ontario, Canada	SW/S	Wetland	In-out	WB	AGR: recharge was found in the eastern portion of the wetland (p.225)	AGR: =
Hollis (1990)	Nigeria	FP	Floodplain	In-out	WB	AGR: the seasonally flooded floodplains provide 1400 x 10^6 m^3 of recharge to the Chad formation (p.418)	AGR: =
Demissie *et al.* (1991)	Illinois, USA	General	Wetland	Multiple	LTH	FPLM: peakflows decrease with increasing wetland FEV: flood volumes decrease with increasing wetland DPFV: wetlands consistently increased low flows (p.949)	FPLM: - FEV: - DPFV: +
Demissie & Khan (1991)	Illinois, USA	General	Wetland	Drained	LTH	FPLM: in their pre-drained state, wetland reduced flooding. DPFV: in their pre-drained state, wetlands reduced low flows (p.1050)	FPLM: - DPFV: -
Faulkner & Lambert (1991)	Zimbabwe	GW/S	Dambo	Same	WB	AGR: total amount of water lost from the dambo to groundwater is small DPAE: dry season evaporation was approximately 50% higher from the dambo than from dryland (p.153-5)	AGR: X DPAE: +
Hensel & Miller (1991)	Illinois, USA	GW/S	Pond	In-out	$Comp_{GW}$	AGR/DPFV: seepage from the two ponds overlying impermeable till is insignificant. Seepage from the two ponds overlying permeable sand and gravel is large enough to double groundwater discharge (p.313)	AGR: . AGR: + DPFV: +
Nielsen *et al.* (1991)	India	FP	Floodplain	With-out	CCM	FPLM/WPGR: flood volumes decrease due to large retention and infiltration losses on the wide sandy flood plains (p.274)	FPLM: - WPGR: =
R*obinson* et al. (1991)	Germany	GW/S	Peat	Drained	WB	MAF/MAAE/FPLM/DPFV: drainage of wetlands increased flows and reduced evapotranspiration losses. Peak flows were greater and low flows were higher (p.275)	MAF: - MAAE: + FPLM: - DPFV: -
Boeye & Verheyen (1992)	Belgium	GW/D	Fen	$Comp_{ET}$	WB	DPAE/DPFV: summer evapotranspiration is a major output - the water table drops and direct runoff disappears (p.161)	DPAE: + DPFV: -

Bullock (1992a)	Zimbabwe	GW/S	Dambo	Multiple	LTH	MAF: dambos are an indiscrimatory factor in determining the volume, persistence and variability of annual runoff DPFV: dambos do not maintain dry-season low flows and reduce low flows where they occur in association with regolith with significant baseflow components FPHM: the impact of dambo on flood magnitude, variability and frequency is insignificant (p.349)	MAF: . DPFV: . DPFV: - FPHM: .
Bullock (1992b)	Zimbabwe	GW/S	Dambo	Same	$Comp_{ET}$	DPAE: evaporation losses in August 1986 are 1 mm day-1 higher on the dambo margins than the central dambo and interfluve vegetation. (p.389)	DPAE: +
Grillot & Dussarrat (1992)	Madagascar	GW/S	Peat	Same	WB	AGR/GDS: fluxes between aquifers vary between downward and upward directions during the year (p.321).	AGR: = GDS: =
Klepper (1992)	Indonesia	FP	Floodplain	With-out	CCM	FVa: the frequency distribution of river levels without swamps is considerably broader than the actual situation. MAF: without swamps, MAF decreases (p.322)	FVa: - MAF: +
Price (1992)	Newfoundland, Canada	SW/S	Blanket bog	Same	WB	AGR:6% of losses was to groundwater seepage FVa: pipe-flow and high near-stream gradients coupled with the high transmissivity produce a flashy gradient (p.103)	AGR: = FVa: +
Bucher *et al.* (1993)	Paraguay R., S. America	FP	Pantanal	In-out	LTH	FVa/MAAE/MAF: modification of the Panatanal may lose its condition of natural sponge responsible for exceptional stability of flow A faster passage of water may also decrease evapotranspiration and increase the amount of outflow (p.36).	FVa: - MAAE: + MAF: -
Eggelsmann et al. (1993)	Germany	SW/S	Mires	Paired	WB	MAAE/MAF: mires are characterised by high evporation and correspondingly low runoff relative to mineral soils AGR: mires are not important in the regeneration of groundwater. Seepage rates from mires to deep groundwater is 80 to 50% lower in mires than in sandy soils (p.234-6).	MAAE: + MAF: - AGR: -
Gibson *et al.* (1993)	NW Territories, Canada	SW/S	Wetland	$Comp_{WC}$	Chem	DPFV: wetland rivers commonly freeze by mid-October and negligible flows occur during winter (p.216)	DPFV: .
Gilvear *et al.* (1993)	England, U.K.	GW/S	Fen	In-out	WB	GDS: groundwater inflow accounted for about 90% of water inputs FVa/DPAE/DPFV: seasonal pattern of wetland outflow mirrors that of groundwater inflow, though amplitude of change is greater because high evapotranspiration depletes surface outflow during the summer (p.325-6)	GDS: = FVa: + DPAE: + DPFV: -
John *et al.* (1993)	West Africa	FP	Floodplain	In-out	LTH	FPLM: the peak is flattened by vast areas of swamp vegetation MAF/MAAE: the water budget of the Massenya floodplain has inflow of 1.7 10^9 m^3 and outflow is 0.8 10^9 m^3; the water budget of the Yaere floodplain is inflows 3.2 10^9 m^3 and outflow is 1.1 10^9 m^3 (p.52,67)	FPLM: - MAF: - MAAE: +
Phillips & Shedlock (1993)	Delaware, USA	GW/D	Ponds	$Comp_{GW}$	$Comp_{GW}$	GDS: the hydrology of shallow seasonal ponds is strongly influenced by the adjacent groundwater-flow system (p.176)	GDS: =
Shedlock *et al.* (1993)	Indiana, USA	GW/S	Fen	$Comp_{GW}$	CCM	AGR/GDS: the interior of Great Marsh are discharge zones, whereas the margins are recharge areas during wet periods. (p. 152)	AGR: = GDS: =

Waddington *et al.* (1993)	Toronto, Canada	GW/S	Swamp	Comp$_{GW}$	Chem	FEV: saturated overland flow from permanently saturated areas created by discharging groundwater was the major storm runoff mechanism (p.37)	FEV: +
Woo & Rowsell (1993)	Saskatchewan, Canada	GW/S	Prairie slough	In-out	WB	AGR: prairie depressions are likely more effective for groundwater recharge than the uplands (p.205)	AGR: +
Woo & Winter (1993)	Permafrost USA	SW/S	Wetland	Same	LTH	FEV/FRR: the magnitude and duration of overland flow in wetland areas are likely to be greater than in uplands because the higher degree of saturation... and gentler gradients (p.28)	FEV: + FRR: -
Hey *et al.* (1994)	Illinois, USA	SW/S	Constructed	Same	WB	AGR: seepage was very low (0-6%) as a component of outflow (p.340)	AGR: X
Iritz *et al.* (1994)	Sweden	GW/S	Peat	Drained	CCM	FPLM: Swedish rivers showed decreased peak flows after drainage because of lowered groundwater. Peat in the Huhtisuo catchment had different topography and special hydraulic characteristics which resulted in an increase in peak flows. The effects of peat drainage on floods were negligible in the Svartan basin.The effect of drainage depends on the groundwater level (p.657-9)	FPLM: + FPLM: . FPLM: -
Johansson & Seuna (1994)	Sweden and Finland	GW/S	Sweden: bogs Finland: fens	Drained	CCM	Sweden: FPLM/MAF: neither peaks nor runoff differed DPFV: summer low flows were slightly higher Finland: FPML: there was a slight increase in peaks DPFV: there was a slight increase in low flows MAF: total runoff volume increased by 3.5% (p.62-66)	FPLM: . FPLM: - MAF: . MAF: - DPFV: -
Price & Maloney (1994)	S.E. Labrador, Canada	GW/S	Domed bog and fen	In-out	Comp$_{GW}$	FEV: storm flows flooded the fen and water was quickly discharged. DPAE: the large depression and detention storage of both systems enhanced evapotranspiration losses (p.328)	FEV: + DPAE: +
Burt (1995)	UK	SW/S	Peat	Multiple	LTH	Flow duration curves from peat-covered basins comparatively demonstrate DPFV: minimal baseflow in summer because there is virtually no drainage from the peat (or clay) FPLM: very high flood runoff given widespread production of surface flow FVa: steep slope and therefore greater flow variability (p.25-26)	DPFV: - FPLM: + FVa: +
Doss (1995)	Maine, USA	GW/D	Bog	Comp$_{GW}$	LTH	AGR: the volume of water that discharges through the basal peat into the mineral sediments may be low (p.224)	AGR: X
Khan (1995)	Malaysia	FP	Floodplain	Same	WB	AGR: groundwater recharged from the swamp will be less than from surrounding areas (p.29)	AGR: -
Meigh (1995)	Botswana	FP	Floodplain	Same	CCM	MAF/MAAE: the wetland was a major cause of water loss from the Bokaa catchment losing about 12 $Mm^3\ yr^{-1}$ DPAE: the wetland is recharged by river flows and loses water by evapotranspiration through the dry season (p.38)	MAF: - MAAE: + DPAE: +
Owen (1995)	Wisconsin, USA	SW/S	Peat	In-out	WB	AGR: wetland did not make substantial contributions to recharge FPLM: the wetland did not play an important role in attenuating flood peaks DPFV: the wetland did not make significant contributions to streamflow under low river flow conditions (p.185)	AGR: X FPLM: . DPFV: .
Thompson & Hollis (1995)	Nigeria	FP	Floodplain	Same	WB	AGR: the wetlands play a vital role in aquifer recharge. The key is the annual wet season flooding (p.97)	AGR: =

Hollis (1996)	Senegal	FP	Floodplain	Same	WB	AGR: the surface aquifer is recharged by the vertical percolation of floodwater (p.172)	AGR: =
Gerla and Matheney (1996)	North Dakota, USA	SW/D	Wetlands around lakes	$Comp_{GW}$	CCM	WPGR/DPGR/GDS: Results show that groundwater flow into the Lake ranged from –0.030m3/day during the late winter to +0.043m3day several times during the summer (p 914)	WPGR: + DPGR: - GDS: =
Gonthier (1996)	Eastern Arkansas, USA	FP	Floodplain	In-out	$Comp_{GW}$	AGR: During a significant percentage of the monthly water level measurements surface water inundating the wetland had sufficient hydraulic head to flow through the confining unit and the upper part of the alluvial aquifer to the lower part of the alluvial aquifer and away from the Black Swamp (intermediate recharge).The greater the distance from the river, the less likely the groundwater from the site will flow to the river and the more likely it will flow to the lower part of the aquifer (p 338)	AGR: =
Hunt *et al.* (1996)	Southwestern Wisconsin	FP	Floodplain	In-out	WB	GDS: Groundwater inflow rates range from 0.2-0.8 cm/day on the site with areas of higher inflows located closer to the river (p. 505).	GDS: =
Hodnett *et al.* (1997)	Amazonia, Brazil	FP	Floodplain	$Comp_{GW}$	$Comp_{GW}$	GDS: floodplain water levels are controlled primarily by discharge of groundwater which maintains dry season streamflow	GDS: =
Matheney and Gerla (1996)	North Dakota, USA	SW/D	Wetlands around lakes	$Comp_{GW}$	CCM	AGR/GDS: although hydraulic gradients are upward over most of the year, discharge of water from the Dakota aquifer contributes less than a few tenths of a percent to the wetland water budget… the recharge-discharge function of Lunby and Stewart wetland is in a state of dynamic equilibrium (p. 119) WPGR: deep penetration may occur during repeated, relatively brief periods of reversed hydraulic gradient corresponding to spring recharge and periods of above normal rainfall (p. 118).	AGR: = GDS: = WPGR: =
Walton *et al.* (1996)	Eastern Arkansas, USA	FP	Floodplain	In/out	LTH	FTTP: Hydrograph peaks downstream of the wetland occurred 4 to 8 days later than at the upstream gauge (p.283) FPLM: The mean reduction in peak discharge between the two gauges was about 20% (p. 283)	FTTP: + FPLM: -
Hooijer (1996)	Shannon, Ireland	FP	Callow	$Comp_{T}$	$Comp_{T}$	FEV: The floodplains “have a considerable flood control capacity; if the minimum 3500ha of callow land is flooded to an average depth of 1m, this represents a storage equivalent to one day of Shannon peak discharge (around $400m^3s^{-1}$)” (p. 195)	FEV: -
Hamilton *et al.* (1997)	Pantanal, Brazil	FP	Floodplain	WB	In-out	MAAE: discharges of inflowing rivers is approximately equal; to the outflow from the Pantanal on an annual basis…water lost by evaporation is roughly balance by direct precipitation (p. 258)	MAAE: +
Logan and Rudolph (1997)	La Plata, Argentina	SW/D	Marshes	$Comp_{GW}$	CHEM	AGR: vertical gradients in the marsh are generally downward throughout the year, suggesting that the Marsh is a predominantly groundwater recharge area, especially the lower lying, wetter areas (p. 229).	AGR: =

Hayashi *et al.* (1998a and 1998b)	Saskatchewan, Canada	GW/D	Slough	In-out	CHEM/ WB	AGR: The vertical hydraulic gradient was downward throughout the year…leading to a total of loss of the system to groundwater of 480mm although only 2mm of groundwater flux becomes net groundwater recharge to the aquifer; the rest is transferred to the surrounding vegetated areas where it is evaporated MAAE: evapotranspiration in the upland planted with wheat is greater than in the wetland (380mm versus 300mm) (p. 53).	AGR: = MAAE: -
Hillman (1998)	Alberta, Canada	FP	Floodplain	In/out	SEH	FPHM: Flow downstream of the wetland was 6% of the peak flow upstream (0.953 m^3s^{-1} downstream compared with 15 m^3s^{-1} upstream of the wetland area). (p.53). FEV/FTTP: the wetland greatly attenuated the flood wave in terms of volume and timing (p. 53).	FPLM: - FEV: - FTTP: +
Ferrari *et al.* (1999)	Aral Sea, Uzbekistan	FP	Deltaic floodplain	In-out	WB	MAF/FPLM: The addition of wetlands in model grid boxes reduced both mean and summer peak flows (p. 1874).	MAF: - FPLM: -
Genereux and Slater (1999)	Everglades, USA	General	Canal	In-Out	WB	AGR: between 50-90% of water entering the canal each month was seepage from the target wetland (p. 166)	AGR: =
Gerla (1999)	Central Minnesota, USA	GW/S	Headwater wetlands	$Comp_{GW}$	$Comp_{GW}$	GDS: On the Shingobee river, wetlands around the river provide 46.3l/s on average to a stream where flow is about 200 l/s. (p. 400).	GDS: =
Hardy *et al.* (2000)	Devon, England	FP	Floodplain	In-Out	SEH	FPLM: floodplain reduced flood peak by 7% (p.212) FPHM: floodplain reduced flood peak by 19% (p. 212) FTTP: For two events, floodplain increased lag by 35 and 4 hours respectively (p.212).	FPLM: - FPHM: - FTTP: +
Raisin *et al.* (1999)	North-east Victoria, Australia	GW/S	Reed swamp	In-Out	WB	DPFV: although flow into the wetland was negligible over extended periods…a baseline discharge from the wetland of around 0.65 ML day was usually measured (p. 139) GDS: During the relatively dry detailed study period the groundwater flow component comprised an estimated 97% of the surface flow leaving the wetland (p. 139)	DPFV: + GDS: =
Spieksma (1999)	Lower Saxony, Germany	SW/S	Bog	Drained/ Pair	LTH	DPFV: The previous data show that most water yield is produced during winter and that perennial storage is not available to sustain flow during dry periods… rewetted raised bogs are not very effective as long term storage areas and regulators of stream flow DPAE: Water yields during summer were usually zero or very low, since most of the summer rainfall was lost through evaporation and transpiration. GDS/AGR: groundwater flow is not a typical feature of raised peat bogs	DPFV: - DPAE: + GDS: x AGR: x
Taylor and Howard (1999)	Uganda	GW/S	Swamp-filled drainage channels	Pair	LTH	WPGR: Between 1988-1993, recharge occurred only in one year and was dependant upon years of exceptionally heavy rainfall (p. 46). MAF: Surface runoff in the Aroca catchment (with wetlands) is 3mm compared to 34mm in the Nyabesheki catchment (without) (p. 67). MAAE: Isotopic data show that river waters have been subjected to significantly less evaporation than wetland waters…surface water have a prolonged residency, which leads to greater exposure to evaporation (p. 66).	WPGR: = MAF: - MAAE: +

Choi and Harvey (2000)	Everglades, USA	SW/D	Drainage channel	In/out	CHEM, WB	AGR/GDS: Estimated net groundwater fluxes were almost entirely negative values indicating that ground-water recharge commonly exceeded ground-water discharge…approximately 31% of the water supplied provides recharge to the underlying aquifer system. Groundwater discharge was negligible in comparison (2.8%) (p. 510)	AGR: = GDS: =
McCartney (2000)	Zimbabwe	GW/S	Dambo	In/out	WB	FEV: "… saturation overland flow, arising within the area of the dambo, is the principal mechanism of storm runoff generation"	FEV: +
Riekirk and Korhnak (2000)	Florida, USA	FP	Pond cypress wetlands	In/out	WB	AGR: Annual deep seepage into the underlying aquifer was 17cm $yr^{-1}$for two wetlands, but in wetland N, underlain by a thick layer of blue clay this was only one cm yr^{-1} (p. 452).	AGR: =
Wolski (2002)	Okavango, Botswana	FP	Swamp	$Comp_{GW}$	$Comp_{GW}$	AGR: "…shallow groundwater is recharged by infiltration and lateral flow from the floodplain. A difference in flood level of 0.6m was accompanied by a difference in groundwater storage, expressed in terms of groundwater level of at least 3m."	AGR: +