Land use, climate change and water availability: Phase 2a

Rapid Evidence Assessment: Results and synthesis

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Disclaimer

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The REA team is based at the Centre for Ecology & Hydrology (CEH). The team is lead by David Boorman and includes Helen Houghton-Carr and Kay Heuser. James Miller has provided advice and guidance to the team.

The REA team reports to a Project Board which is lead by Henry Leveson-Gower (Defra) and includes David Boorman (CEH), Ian Holman (Cranfield University), Andrew Hughes (British Geological Survey; BGS), David Seccombe (Environment Agency; EA) and Rob Soley (AMEC).

Executive summary

This report presents the results from a Rapid Evidence Assessment (REA) to address the question "Can land use and land management make a difference to water availability?"

Conclusions from this review are:

- It may take many decades for the impacts of land use and land management practices on surface and groundwater resources to become apparent.

- Trees never use less water than other vegetation, and usually use more water, leaving less water for surface runoff and groundwater recharge. Any land use/management intervention that promotes tree growth will use more water. Mature forests use less water than growing forests, and plantation forestry goes through stages, some of which (drainage and felling) can increase runoff and recharge.

- The key messages from the biofuels articles are that there is no clear evidence about the water use of *Miscanthus* and switchgrass compared to traditional crops in the UK, but there is evidence that short rotation coppice (e.g. willow) can use very much more water than traditional crops.

- Land use that leaves bare soil reduces evaporation and increases surface runoff or groundwater recharge.

- Small (field) scale interventions to hold more water locally in the soil (e.g. tillage practices, soil treatments) are generally successful. This has the effect of reducing surface runoff and groundwater recharge, with the extra water being available for crops.

- Some agricultural land use/management practices are dependent on very location-specific conditions, and are not regarded as replicable in other places. Other practices, whilst replicable, may not produce the same results because of different physical and climatic characteristics. Potential impacts of change may need to be considered on a case-by-case basis.

- All of the above impacts are generally localised, with what appear to be large changes at the field, plot or sub-catchment level manifested as only small changes at the catchment or basin level.

Concerning the process used to reach these conclusions the following recommendations are made:

- The primary question and initial scoping to determine feasible search parameters are critical: future REAs should explicitly include stakeholder consultation from an early stage in order to better to understand the question. Focusing this review solely on UK studies would have significantly reduced the number of articles in the final set. To increase the number of UK articles, it would have been necessary to widen the search.

- Future REAs should concentrate on a particular land use or land management intervention (e.g. tillage practices, certain crops, land drainage, etc), and on a particular hydrological or hydrogeological impact, which may facilitate a broader search and, thereby, consider more articles on that topic, or at a particular geographical location, within the time frame of the review.

It is further recommended that:

- In order to generate a larger body of UK-specific evidence, there is a need for coordinated, targeted research and long-term monitoring to investigate the water-related impacts from the most important land uses and land management interventions, across a variety of catchment types.

- There is a need to consider the impacts of land use and land management on water quality, as well as on water quantity.

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1. Introduction

1.1 Background

A Rapid Evidence Assessment (REA) has been carried out with the initial brief to review the evidence that interactions between climate change and land use and management can affect water availability. The REA aimed to capture as unbiased and comprehensive a sample as possible of published literature to provide an overview of the available evidence. Houghton-Carr *et al.* (2013a) present the protocol detailing the REA objectives and the process that is being undertaken to complete the REA. The protocol discusses the question that guides the scope of the review, the strategy for the search, refinement and extraction of evidence, and the subsequent synthesis of that evidence. Expert opinion is not being used to force the outcome of what is a systematic literature search in any particular direction. Houghton-Carr et al. (2013b) report on the progress implementing the protocol to produce a list of articles for review at full text, and invite the Project Board to nominate additional references. This report describes progress since then, and finalisation of the review results.

1.2 List of Project Board nominations

Each Project Board member was invited to put forward any additional articles considered relevant to the review – a maximum of three per Board member - such as grey literature or specialist papers not uncovered by the search strategy. Guidance was given that the articles must contain original evidence, not just assertion or opinion; must not espouse best practice, without evidence; that modelling studies that only explore simulated changes without supporting data would not supply evidence; and that evidence would only be included once, such that different papers referring to the same data, or repeating results from other papers, would not represent additional evidence.

This mechanism enabled the Project Board members, each as an author, recognised expert and/or practitioner, to provide additional evidence in whatever aspect each considered most important, thus reflecting their individual perspective. In total, nine additional articles were nominated:

- Deeks, L. K., M. A. Clarke, I. P. Holman, N. J. K. Howden, R. J. A. Jones, T. R. E. Thompson and I. G. Truckell (2008). "What effect does soil compaction in grassland landscapes have on rainfall infiltration and runoff?" SEESOIL 17: 11.

- Finch, J. W. and A. B. Riche (2008). "Soil water deficits and evaporation rates associated with Miscanthus in England." Aspects of Applied Biology 90: 8.

- Hickman, G. C., A. Vanloocke, F. G. Dohleman and C. J. Bernacchi (2010). "A comparison of canopy evapotranspiration for maize and two perennial grasses identified as potential bioenergy crops." Global Change Biology Bioenergy 2(4): 157-168.

- Jackson, B. M., H. S. Wheater, N. R. McIntyre, J. Chell, O. J. Francis, Z. Frogbrook, M. Marshall, B. Reynolds and I. Solloway (2008). "The impact of upland land management on flooding: insights from a multiscale experimental and modelling programme." Journal of Flood Risk Management 1(2): 71-80.

- Marc, V. and M. Robinson (2007). "The long-term water balance (1972-2004) of upland forestry and grassland at Plynlimon, mid-Wales." Hydrology and Earth System Sciences 11(1): 44-60.

- O'Connell, P. E., K. J. Beven, J. N. Carney, R. O. Clements, J. Ewen, H. Fowler, G. L. Harris, J. Hollis, G. M. O'Donnell, J. C. Packman, A. Parkin, P. F. Quinn, S. C. Rose, M. Shepherd and S. Tellier (2004). Review of impacts of rural land management on flood generation: Impact study report. Defra R&D Technical Report FD2114/TR.

- Phong, V. V. L., P. Kumar and D. T. Drewry (2011). "Implications for the hydrologic cycle under climate change due to the expansion of bioenergy crops in the Midwestern United States." PNAS 108(37): 6.

- Raymond, P. A., N.-H. Oh, R. E. Turner and W. Broussard (2008). "Anthropogenically enhanced fluxes of water and carbon from the Mississippi River." Nature 451(7177): 449-452.

- Robinson, M., A. L. Cognard-Plancq, C. Cosandey, J. David, P. Durand, H. W. Fuhrer, R. Hall, M. O. Hendriques, V. Marc, R. McCarthy, M. McDonnell, C. Martin, T. Nisbet, P. O'Dea, M. Rodgers and A. Zollner (2003). "Studies of the impact of forests on peak flows and baseflows: a European perspective." Forest Ecology and Management 186(1-3): 85-97.

These additional articles entered the process at the final stage i.e. for review at full text (Section 2.1 onwards) where they were subject to the same review and assessment as the articles identified by the REA search protocol.

1.3 Structure of this report

After this introductory section, Section 2 continues application of the REA protocol to further refine the list of articles for review at full text. The final set of articles was categorised and evaluated as described in Section 3. Section 4 presents the main conclusions and recommendations from the study, including implications for research and policy. The final list of articles informing the outcomes of the study is presented in Appendix 1, with extracted data in Appendices 2 and 3.

2. Application of the final stages of the REA protocol

2.1 Generating the final list of articles

The REA protocol defines a search strategy which aims to capture an unbiased and comprehensive sample of published literature relevant to the primary question within the timeframe of the REA. Figure 2.1 summarises the search strategy and the number of articles at each stage of the process.

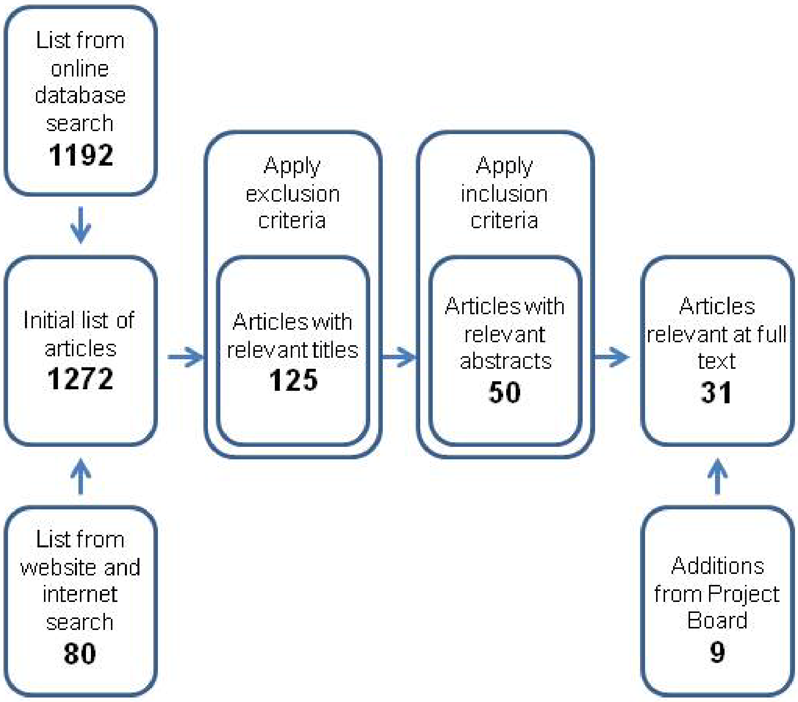

Figure 2.1: Process for refining the search

The 50 articles identified by the REA search protocol, plus the nine Project Board nominations, were viewed at full text. Two reviewers independently assessed each article at full text, reapplying the exclusion and inclusion criteria used previously in the assessments at title and abstract stages (Houghton-Carr *et al.*, 2013b). 27 articles were rejected at this stage because, upon examination of the full text, they did not in fact meet the exclusion and inclusion criteria or, in the case of six of these articles, only the title and abstract were in the English language and the full text was not. The level of agreement between the two reviewers, measured by a statistical technique called kappa analysis, was 0.76 indicating substantial agreement. The seven discrepancies were discussed and resolved by consensus.

The final list of 31 articles informing the outcomes of the study is presented in Appendix 1 and is also available on request as an EndNote X6 folder. The REA protocol has identified these articles as providing the most relevant evidence on whether land use/management makes a difference to water availability.

2.2 Relevance and robustness assessment

The 31 articles assessed to have passed the final stage were assigned relevance and robustness weightings. The relevance and robustness ratings consider both the relevance of the article to the REA primary question and the quality of the methodological approach, which are critical to an objective and transparent assessment of the extracted evidence in the data synthesis.

The relevance of the article and reported research to the REA primary question was assessed using components of the question in addition to location, as outlined in Table 2.1. Similarly, the robustness of the research methodology and reported outcomes was assessed by the criteria presented in Table 2.2. These criteria used to assess the quality of the evidence in the final list of articles required consideration of a number of subjective decisions made by the REA team. Two reviewers independently assessed the relevance and robustness scorings of the articles on the final list. The level of agreement between the two reviewers gave a kappa rating of 0.63, indicating good agreement, and no need to modify the criteria. The few discrepancies were discussed and resolved by consensus.

Table 2.1: Matrix table used to derive confidence in the relevance of selected articles

Component	Low (1)	Medium (2)	High (3)
Location	Countries with dissimilar climatic conditions to UK	Countries with similar climatic conditions to UK	UK
Scale	Any scale, but not explicitly considering water potentially available for human use	Field/plot scale considering water potentially available for human use	Catchment/basin scale considering water potentially available for human use
Subject (population)	Subjective findings based on stakeholders' opinions and perceptions	Change in water availability not quantified, but direction observed	Quantifiable change in surface water/ groundwater availability
Intervention	Land use/management practice not defined	Non-replicable land use/ management practice	Replicable land use/ management practice
Overall score (out of 12)	Overall score should reflect the relevance across the four components		

Table 2.2: Matrix table used to derive confidence in the robustness of selected articles

Component	Low (1)	Medium (2)	High (3)
Objectives of study / hypothesis being tested	No clear objectives (e.g. effect of intervention on water availability is incidental/by-product of study)	General objectives (e.g. investigation of environmental impacts of intervention)	Clear specific objectives (e.g. investigation of effect of intervention on water availability)
Approach - quality of hydrometric monitoring and impact of intervention	Post-intervention hydrometric monitoring only, with/without stakeholder survey	Before /after hydrometric monitoring but no use of control sites/paired catchments, with/without stakeholder survey	Before/after hydrometric monitoring and use of control sites/ paired catchments, plus stakeholder survey
Evaluation - data reporting and analysis	No data quality control; minimal analysis and evaluation of study data; summary review of results	Quality control of data; basic data analysis and evaluation, but no interpretation of impact	Quality control of data; rigorous data analysis and evaluation; evaluation of impact of intervention
Reporting of evaluation	Unpublished, subject to no peer review	Reported in grey literature	Reported in peer-reviewed literature
Overall score (out of 12)	Overall score should reflect the robustness across the four components		

The overall relevance and robustness scores distinguished those articles that are most relevant and have the best quality methods, and as such are ranked highest, from those with little relevance and poor methods, ranked lowest. This provided an indication of the confidence placed by the REA team in the evidence in the selected articles.

The robustness and relevance scorings for each article in the final set are detailed in Appendix 2. To facilitate subsequent analysis and interpretation of results, the articles are classed into four broad topic categories: agriculture, biofuels, forestry and other land use/management interventions.

2.3 Data extraction

The 31 articles assessed to have passed the final stage were processed by extracting data into a predefined spreadsheet template that facilitated recording of the most important details to provide a comprehensive overview. This template included the following details for each article:

- **Title and authors** with full reference or web address (See Appendix 1);
- **Population (subject)** monitored including location and type of site/catchments/basins and measure of water availability and **Intervention** monitored including land use and type of land management intervention;
- **Evaluation methodology** including details of how the monitoring of the water availability has been carried out e.g. use of control sites or paired catchments;
- **Results** summarising the monitored difference (positive, no change, negative) in water availability, and including the numerical value and units that express this change;
- **Conclusions and recommendations** covering the key messages from the article;
- **Confidence scoring** for relevance and robustness of article (see also Appendix 2);
- **Reviewer comments** from REA team.

The main details extracted from each article in the final set are detailed in Appendix 3, again sub-divided by the four topic categories.

3. Analysis of results

3.1 Land use/management intervention

The final set of 31 articles was categorised into four different land use/management topic categories in order to make the subsequent analysis more coherent. Articles were assigned to only one category. Table 3.1 presents the breakdown.

Table 3.1: Topic categories of final set of articles

Topic	REA protocol search results	Project Board nominations	Total	% of overall total
Agriculture	5	2	7	23
Biofuels	1	1	2	6
Forestry	10	2	12	39
Other land use/management	9	1	10	32
Total	25	6	31	

The table shows that forestry and other land use/management interventions each comprise about a one third of the final set of articles, whilst the remaining third is made up of articles on agriculture and biofuels. Biofuels was identified as a separate category to agriculture as this was a topic of particular interest to some members of the Project Board. The "other" land use/management category included papers on drainage, soil properties and application of treatments, sometimes in an attempt to improve soil properties. Six of the nine Project Board nominations were included in the final set, the other three being rejected for one or more of the reasons described in Section 2.1.

3.2 Analysis of article relevance

Figure 3.1 illustrates the breakdown by location, scale, subject and intervention for each land use/management category, according to the scoring in Table 2.1 and Appendix 2.

3.2.1 Location

Across all categories, relatively few articles were from UK-based studies, with a third to half of the articles from countries with dissimilar climatic conditions to the UK, and the remaining third or so from countries with similar climatic conditions to the UK. The six Project Board nominations that reached the final list were all UK-based or from similar countries, so went some way to improving the location relevance distribution; indeed, this is the aspect where the Project Board nominations had most impact.

Much of the available evidence is concentrated in a few regions of the world. Figure 3.2 shows the countries involved in the final set of 31 articles, though there is no distinction between a country with only one case study and a country with several, and also no within-country location which has the effect of favouring larger countries e.g. there is only one study in China, but several in India. In the REA protocol, no restrictions were applied regarding country because it was anticipated that literature from central and northern European countries and non-European countries with similar physical and climatic characteristics to the UK may be directly relevant. However, the unexpected paucity of studies worldwide – but particularly in the UK – suggests that much of the widely-held opinion is based on grey literature, unpublished information and individual perceptions, rather than on primary measurements.

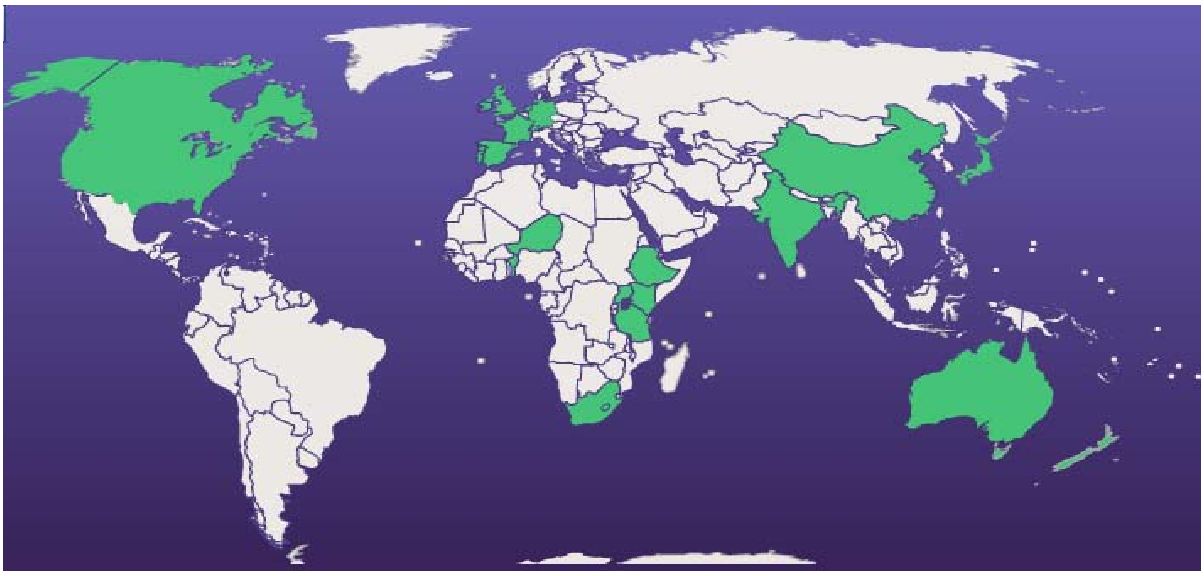

Figure 3.2: Country locations of final set of articles

3.2.2 Scale

For the agriculture and forestry categories, all the articles were from field/plot or catchment/basin scale studies that considered water available for human use. This was not the case for the biofuels and other land use/management categories, where half the articles did not explicitly consider water availability for human use. The Project Board nominations were fairly evenly distributed between the three scale relevance classes.

3.2.3 Subject (population)

The majority of articles presented results showing a quantifiable, or at least directional, change in surface water or groundwater availability. This is not surprising as it is unlikely that many articles would have reached this final stage of the REA protocol without having such content. Despite this, four of the final 31 articles were classed as containing only subjective findings based on stakeholder opinions and perceptions, and were included because, upon reading the full text, it was considered that they still made a useful contribution. One of the Project Board nominations fell into this group. The low subject relevance articles were fairly evenly distributed between the agriculture, forestry and other land use/management categories.

3.2.4 Intervention

The majority of articles described land use/management practices that could be replicated, though in two cases, one in each of the forestry and other land use/management categories, the practices were not clearly defined. However, in the agriculture category, nearly half of the practices were not considered to be replicable, usually because they were dependent on very location-specific conditions, thereby reducing the possibility of transferring the results to other places. Again, one of the Project Board nominations fell into this group.

3.3 Analysis of article robustness

Figure 3.3 illustrates the breakdown by objective, approach, evaluation and reporting for each land use/management category, according to the scoring in Table 2.2 and Appendix 2.

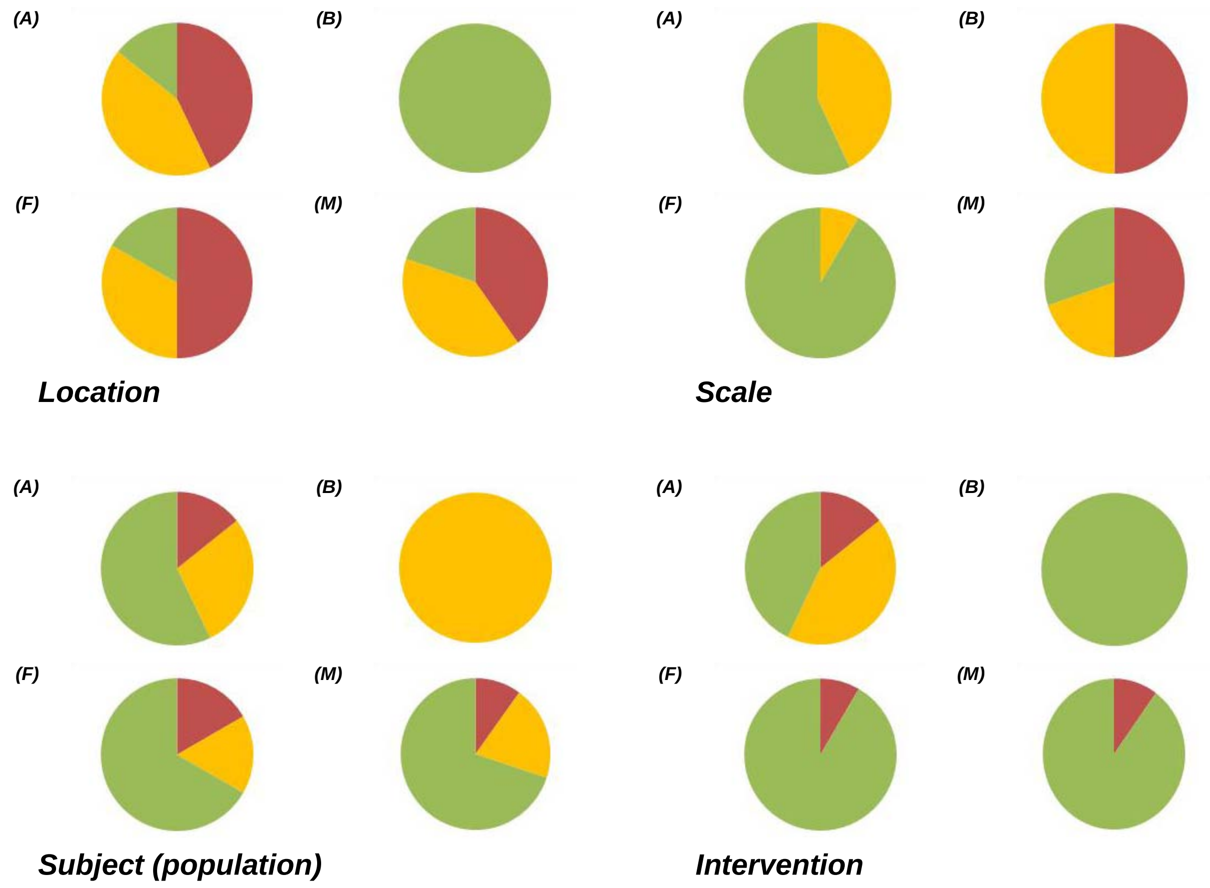

Figure 3.1: Breakdown of relevance categories according to Table 2.1 where red indicates low relevance, amber medium and green high relevance: for each category (A) is agriculture, (B) is biofuels, (F) is forestry and (M) is other land use/management

3.3.1 Objective

For the agriculture, forestry and other land use/management categories, over half of the reported studies had clear specific objectives. The biofuels studies and the remainder of the other land use/management studies had general objectives, looking at the broader impacts of the described interventions, rather than the studies being specifically designed to investigate the impacts of the interventions of some aspect of water availability. In the agriculture and forestry categories, the remaining articles were evenly distributed between studies with general objectives and studies with no clear objectives. The two Project Board nominations in the agriculture category fell into these two classes.

3.3.2 Approach

For the forestry and other land use/management categories, half to three-quarters of the articles were from studies involving before/after hydrometric monitoring, paired catchments or other control sites. This was the case for only a third of the studies in the agriculture category, with the remainder of the agriculture studies and the biofuels studies, and also the remainder of the forestry and other land use/management studies, fairly evenly distributed between those with some form of before/after monitoring but no use of controls and those with only post-intervention monitoring. This reflects and justifies the need for long-term hydrometric monitoring to support research studies (that have not necessarily yet been conceived). The Project Board nominations were fairly evenly distributed between the three approach robustness classes.

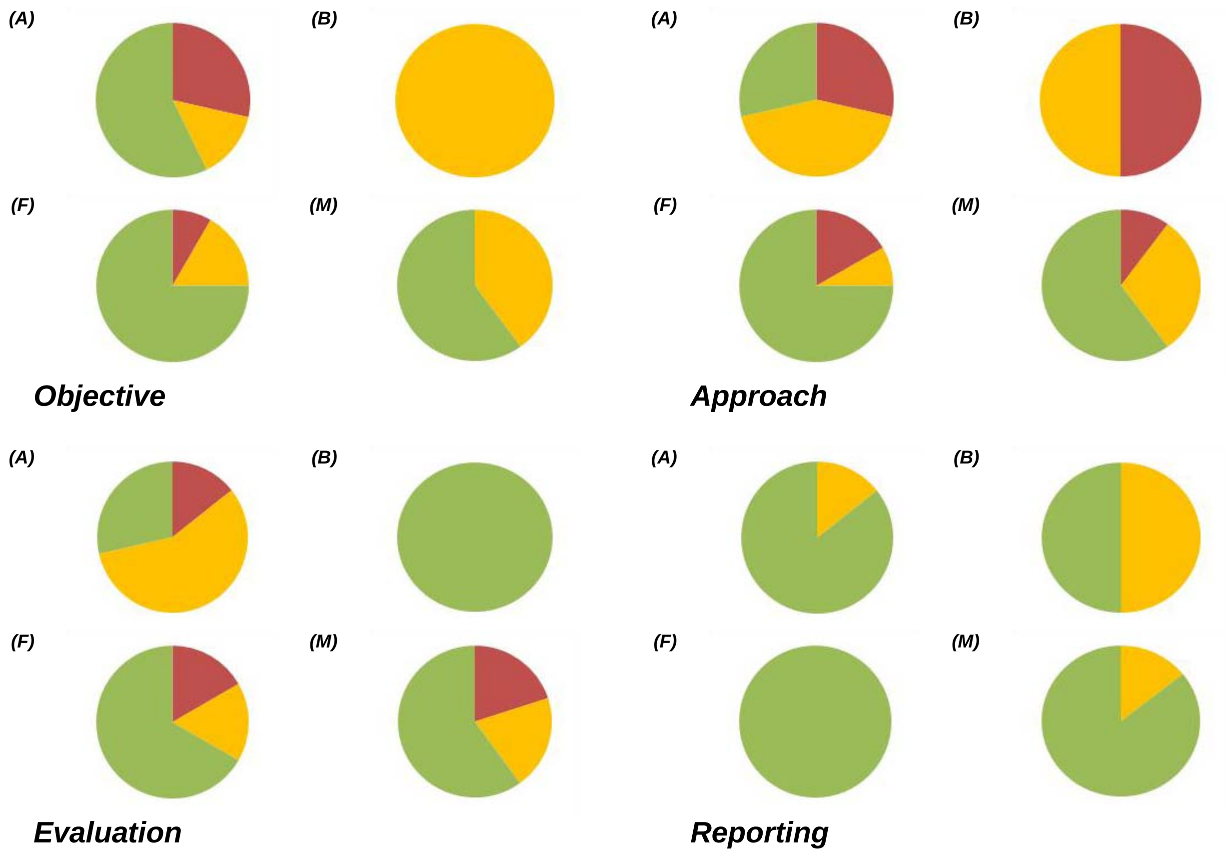

Figure 3.3: Breakdown of robustness categories according to Table 2.2 where red indicates low robustness, amber medium and green high robustness: for each category (A) is agriculture, (B) is biofuels, (F) is forestry and (M) is other land use/management

3.3.3 Evaluation

Between around three-quarters and all of the articles in the biofuels, forestry and other land use/management categories described studies involving quality controlled data, rigorous data analysis and evaluation, and interpretation of the impact of the reported intervention. In contrast, the majority of the articles in the agriculture category presented studies with quality controlled data but only basic data analysis, with no explicit interpretation of the results. This also applied to a small number of the forestry and other land use/management articles. The remainder of the articles in all three categories fell into the low robustness class with no data quality control and minimal analysis and evaluation. One of the Project Board nominations fell into this group.

3.3.4 Reporting

All of the articles were classed as having medium or high reporting robustness, with the majority in the high “peer-reviewed literature” class i.e. published in journals. This is unsurprising as the timeframe for the REA biased the search protocol towards articles published in journals through its focus on online databases. Indeed, of the four medium “grey literature” articles, two were Project Board nominations and the other two were identified from the website search component of the REA protocol.

Analysis of the publication dates of the final set of articles revealed that the oldest article in the list is a forestry paper from 1988 (Sharda et al.), and the most recent an agriculture paper from 2013 (Huang et al.). Figure 3.4 shows the distribution of articles in 5-year periods from 1985 (the last class being incomplete as there are no articles from the remainder of 2013 and 2014). In the REA protocol, no restrictions were applied regarding the year of publication, so the significant difference pre- and post- the year 2000, with 6 articles before and 25 after, may indicate a growing interest in the topic in recent years. Six of the articles were published in the high impact Journal of Hydrology, and the others were even distributed within a variety of other journals.

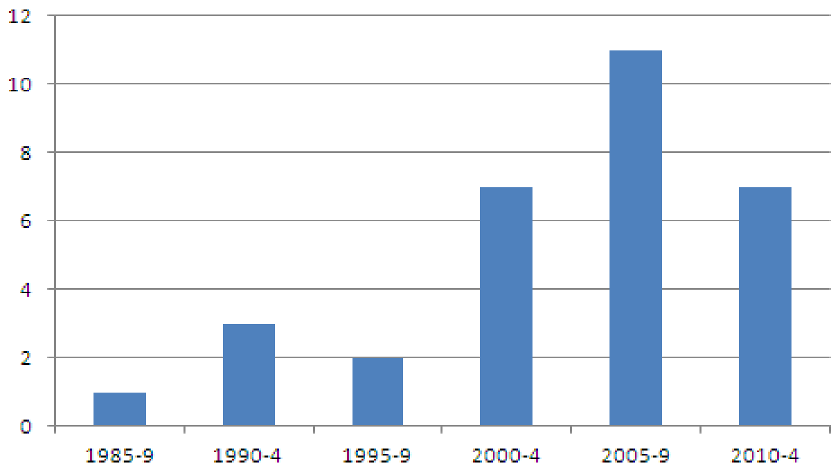

Figure 3.4: Publication dates of final set of articles

3.4 Analysis of extracted information

It should be stressed that the comments in Sections 3.2 and 3.3 are not intended as some form of assessment on the quality of the articles in the final set, but an indication of the relevance and robustness of the evidence presented in those articles, in the context of the REA primary question:

Can land use and land management make a difference to water availability?

Since the articles were not written and published with this specific question in mind, then it is likely that some will be more relevant and/or more robust than others. These articles are the final 31 of an initial 1281 articles (1272 from the REA protocol plus nine from the Project Board). To have reached this stage they all, by definition, contain valuable data and other information which assist in answering the primary question.

3.4.1 Agriculture

On average, the articles categorised as agriculture scored joint lowest for relevance and third out of four for robustness. All of the articles were from field/plot or catchment/basin scale studies, the majority demonstrating quantifiable or directional changes in water availability, and over half of the articles were from studies with specific objectives and based in the UK or in countries with similar climatic conditions to the UK. However, nearly three-quarters of the studies relied on some form of before/after monitoring with no use of control sites or only on post-intervention monitoring, with only basic data analysis and no interpretation of the results in a wider context. Furthermore, nearly half of the reported land use or land management practices were assessed as either location-specific or very general and the results were, therefore, not directly transferrable.

Two articles in the agriculture category looked at the impacts of land use and land management on flooding, rather than on water availability. However, many of the issues raised are of relevance. Using data from the Mississippi basin in the USA, Raymond et al. (2008) consider that impacts from changes in land use and land management are potentially more important than from changes in climate. Using primarily UK studies, O'Connell et al. (2004) cite substantial evidence that land use and land management practices affect runoff at the local scale, but limited evidence that these effects are felt downstream. They go on to highlight the need for data collection and modelling studies to support the development of methods to predict the impacts. Scanlon et al. (2007) also highlight the need to consider the impacts of land use and land management practices on water quality as well as water quantity.

The REA exclusion criteria purposefully omitted articles about water management as the focus of the question is land use and land management. However, Aarts et al. (2000) provide evidence that strict management of water for agriculture on a case-by-case basis, will leave more of the water resource available for other uses which may have associated economic benefits.

Huang et al. (2013), Leblanc et al. (2008) and Scanlon et al. (2007) all note that it may take many decades, or even hundreds of years, for the impacts on runoff and groundwater recharge of changes in land use and land management to become apparent. Whilst some of these articles are based on studies in semi-arid and tropical locations with very different climatic and physical conditions to the UK, their point about a time lag is still relevant.

The key message from the articles categorised as agriculture is that row crops generally use less water than pre-existing natural vegetation, the general explanation being that any bare soil reduces evaporation and the extra available water contributes to either surface runoff or groundwater recharge. One study out of seven showed the opposite impact, but this was in a semi-arid region of China so not relevant to the UK.

3.4.2 Biofuels

On average, the two articles categorised as biofuels scored second out of four for relevance and lowest for robustness. The articles – Finch & Riche (2008) and Finch et al. (2004) – present much of the same evidence, largely concerned with the water use of biofuel crops compared to other crops and land cover typical of the UK. They conclude that interception and transpiration are both important factors influencing water use. Energy grass crops, such as *Miscanthus* and switchgrass, use the same or less water than, for instance, grass and maize, but although *Miscanthus* transpires less, its interception losses are higher. The articles report replicable field/plot scale studies, the results of which demonstrate directional changes, but there is no information available about whether the observed impacts are also seen at a catchment/basin scale, highlighting the need for further work to assess the impact of biofuel crops on water resources. Stone et al. (2010) consider that all aspects of water requirements and water resources should be taken into account in biofuel production.

The key messages from the articles categorised as biofuels are, firstly, that there is no clear evidence about the water use of *Miscanthus* and switchgrass compared to traditional crops in the UK and, secondly, that short rotation coppice (e.g. willow) grows rapidly and can use very much more water than traditional crops.

3.4.3 Forestry

On average, the 12 articles categorised as forestry scored highest in both the relevance and the robustness assessments, and presented some of the most consistent results as well as the highest scoring individual articles. All of the articles were from field/plot or catchment/basin scale studies, the majority demonstrating quantifiable or directional changes in water availability as a result of replicable land use or land management practices, and half of the articles were from studies with specific objectives and based in the UK or in countries with similar climatic conditions to the UK. Over three-quarters of the studies relied on some form of before/after monitoring, paired catchment or other control sites, with data quality control and rigorous data analysis and interpretation of results.

All the articles agreed that afforestation and deforestation affect surface water and groundwater, and that the effect depends on the age and type of tree, and the stage of the typical commercial forestry management cycle (i.e. draining, planting, maturing, felling), in addition to other factors such as the geology, soils, climate, natural vegetation, etc. The highest scoring paper from the REA review, Marc & Robinson (2007), nominated by the Project Board, capably demonstrates the age-related findings with reference to the long-term (1971-date) Plynlimon paired catchment study in Wales, UK, as does another long-term monitoring study, that of Scott & Prinsloo (2008) in South Africa (1942-2003), who go on to consider the potential uses of longer rotations in management cycles. Indeed, the forestry articles cover a large geographical range with two others in Europe, three in India, one in Japan, two in Australasia, one in the USA and one review paper, in addition to the UK and South Africa studies mentioned previously.

The aspects of most interest concern the impact of the forestry on peak flows and baseflow, often considered in association with the impact on evapotranspiration, and Table 3.2 summarises the results from these 11 articles (excluding the Whitehead & Robinson (1993) review paper), identified by the REA protocol and the Project Board. The number of supporting papers may seem low, but the majority of articles cover only particular stages of the management cycle or components of the water balance or flow regime. At first glance, Table 3.2 appears to conflict with the equivalent table presented in Whitehead & Robinson (1993), but Table 3.2 attempts to present impacts at different stages of the management cycle and tree age, whereas Whitehead & Robinson (1993) summarise impacts for afforestation and deforestation with no sub-division so it is difficult to make a direct comparison.

Table 3.2: Impact of forestry on evaporation and flows (arrow indicates direction of change and number in brackets indicates the number of supporting papers)

	Drainage	Planting	Maturing	Felling
Evaporation	-	↑ (2)	-	↓ (2)
Total flow	↑ (1)	↓ (4)	No change (1)	↑ (3)
Peak flow	↑ (1)	↓ (2)	-	↑ (3)
Baseflow	↑ (1)	↓ (1)	No change (1)	↑ (2)

Amongst those articles that care to speculate, there is broad consensus that changes in runoff or total flow are strongly influenced by changes in baseflow, augmented by drainage channels, rather than in surface runoff (Dung et al., 2012; Marc & Robinson, 2007; Robinson et al., 2003). Of course, surface runoff is also affected, though Marc & Robinson (2007) detected no changes in peak flows and Sikka et al. (2003) suggested that the effect of forestry on peak flows becomes less significant at higher return periods. Several authors make the point that the impacts of forestry on flow are fairly localised and that, whilst they may appear significant at a sub-catchment scale, they are diluted at the basin scale where it is normal practice to phase the management cycle across a basin such that different subcatchments are at different stages of the cycle.

Ruprecht & Schofield (1991) are also interested in the impact on groundwater levels and provide evidence from Australia that different types of clearing and thinning can cause groundwater levels to rise compared to those under control forestry, but acknowledge that geology may play a significant role. Narain et al. (1998) notes that groundwater recharge in

India is reduced by afforestation with fast-growing species on formerly agricultural land. Stewart & Fahey (2010) show that deep aquifers in New Zealand appear to be less affected by afforestation than shallow aquifers, though this may be an indication that the impacts of the change may take a long time to become apparent, reiterating the comments about time lag from Section 3.4.1.

The key message from the articles categorised as forestry is that trees never use less water than other vegetation, and usually use more water, leaving less water for surface runoff and groundwater recharge. Hence, any land use/management intervention that promotes more tree growth will use more water. Mature forests use less water than growing forests, and plantation forestry goes through stages, some of which (drainage and felling) can increase runoff and recharge.

3.4.4 Other land use/management

On average, the ten articles in this category scored joint lowest for relevance and second out of four for robustness. All of the articles were based on studies from a range of scales, half of which did not explicitly consider water availability for human use, being concerned with replicable practices such as land drainage (2 articles), soil management (5) or other soil treatments (3). Despite this, the majority reported quantifiable or directional changes in water quantity. Over half of the articles were from studies with specific objectives and based in the UK or in countries with similar climatic conditions to the UK. Over half of the studies used some form of before/after monitoring, paired catchment or other control sites, with data quality control and rigorous data analysis and interpretation of results.

Land drainage is likely to precede a change in land use. Holman (2002) reviews the impacts of land drainage on groundwater recharge in the UK at a variety of scales and comments that there is potential for drainage to alter the timing and duration of water fluxes, such as recharge. Prevost et al. (1999) and Robinson et al. (2003) present evidence that land drainage appears to cause an increase in baseflows. Changes to recharge and surface flows can affect the water balance and, hence, water availability.

Five articles reported the results of studies investigating the impacts of different soil management practices. DeLaune & Sij (2012), Gregory et al. (2005) and Temesgen et al. (2012) all present field-scale studies to investigate the impact of different tillage practices (e.g. no till, conventional tilling, strip tilling, aeration, subsoiling, crop rotation) in semi-arid regions of the USA and East Africa. There is evidence that conventional tillage increases the onset and volume of runoff, compared to no till (DeLaune & Sij, 2012; Temesgen et al., 2012), but this can be reduced by strip tillage, and even more by strip tillage with subsoiling (to break plough pans) (Temesgen et al., 2012), but there is no information available about whether the observed impacts are also seen at a catchment/basin scale.

Deeks et al. (2008) considered the impacts of livestock grazing and report evidence that the intensity and duration of land use for grazing directly affect soil compaction, soil erosion and the volume of surface runoff. However, large increases in runoff at the field scale may appear as only small changes at the catchment scale. Giertz et al. (2005) explain the increased soil erosion and runoff from an agricultural catchment in West Africa, in a paired catchment study, by the reduced activity of macrofauna (e.g. earthworms) that are killed off by the cultivation and which, in turn, reduces macroporosity, permeability and infiltration capacity of soil.

Three articles assessed the impacts of different soil treatments. Lozano-Garcia et al. (2011) and Martínez et al. (2003) present similar studies assessing the impacts of treating soils with olive mill wastes and urban organic wastes, respectively, in Spain. In both cases, significantly less runoff was observed from the treated areas compared to the untreated areas, showing that treatments to improve soil physical properties can have a notable impact, though there may be issues concerning water quality. Davis (1993) examines the impacts of treating chaparral (scrubland) in the USA with herbicide, vegetation in the treated areas being replaced with grassland, and reports a doubling in runoff volume, without having adverse effects on water quality because of the dilution by runoff from untreated land.

The key message from the articles categorised as other land use/management is that small-scale interventions to hold more water locally in the soil (e.g. tillage practices, soil treatments) are generally successful – at the local scale. This has the effect of reducing surface runoff and groundwater recharge, with the extra water being available for crops.

4. Outcomes from REA

4.1 Conclusions

The initial list of 1272 articles and nine nominations from the Project Board was refined to 31 articles identified as providing the most relevant evidence on whether land use/management makes a difference to water availability. The consistency of and confidence in the selected evidence varied between the four land use/management topic categories used to analyse the results. The land use and land management interventions assessed in the REA were agriculture, biofuels, forestry and other land use/management practices (such as drainage, tillage and soil treatment). Evidence from the wide range of studies considered in this review is not necessarily UK-relevant and sometimes highly location-specific, making it difficult to draw other than general conclusions to address the primary question.

The final set of 31 articles included seven from the UK (one in agriculture and two in each of biofuels, forestry and other land use/land management). The remaining articles were divided fairly equally between those from countries similar to the UK in terms of physical and climatic characteristics, and those from countries dissimilar to the UK. Hence, not all of the selected evidence is useful for current UK conditions.

The final set of articles was not large, demonstrating a lack of long-term monitoring studies making observations and collecting data, whilst a number of the articles rejected at earlier stages were modelling studies based on minimal, if indeed any, primary measurements. Studies involving a robust experimental approach with control sites, paired catchments and/or before/after monitoring were most common in the forestry and other land use/management categories. The forestry papers demonstrated the most consistent results, possibly reflecting the fact that they were generally supported by more data than studies in the other categories.

The data available from the final set of articles were limited in both duration and frequency of measurement, with a lack of long-term continuous time series that would allow systematic characterisation of temporal changes in water availability. Exceptions to this generalisation usually involved studies concerned with impacts of afforestation and deforestation. Few of the studies made any attempt to estimate uncertainty, and the approach and evaluation scoring are based upon the REA team's subjective assessment of clarity of method and accuracy of measurement.

25 of the 31 articles considered were published in or after the year 2000, perhaps indicating a growing interest in the topic by funding agencies and researchers. However, this may also demonstrate that it takes many years to collect data which may (or may not) show significant trends requiring a commitment to collecting long-term continuous datasets in order to draw meaningful conclusions about the impacts of change.

Conclusions from this review are:

- There is evidence from several papers, in both the agriculture and forestry categories, that it may take many decades, if not longer, for the impacts of land use and land management practices on surface and groundwater resources to become apparent. Some of the forestry papers had the advantage of relatively long datasets which enabled them to examine how the impacts of afforestation on surface and groundwater vary with the age of trees, as well as with the stage of the typical forestry management cycle.

- The key message from the forestry articles is that trees never use less water than other vegetation, and usually use more water, leaving less water for surface runoff and groundwater recharge. Hence, any land use/management intervention that promotes more tree growth will use more water. Mature forests use less water than growing forests, and plantation forestry goes through stages, some of which (drainage and felling) can increase runoff and recharge.

- Studies with a specific water availability-related objective were most common in the forestry category, slightly less in the agriculture and other land use/management categories. Many of these studies were not designed to assess impacts of an aspect of water related to ultimate use. The biofuels papers, in particular are very much focused on crop water use without any consideration of wider catchment-scale impacts and implications.

- The key messages from the biofuels articles are that there is no clear evidence about the water use of *Miscanthus* and switchgrass compared to traditional crops in the UK, but there is evidence that short rotation coppice (e.g. willow) can use very much more water than traditional crops.

- There is evidence from several papers, in the agriculture, forestry and other land use/management categories, that impacts are fairly localised, with what appear to be large changes at the field, plot or subcatchment level manifesting themselves as only small changes at the catchment or basin level. Since water resources and water availability are normally assessed at the catchment or basin scale, this raises the additional issue of what scale the primary question is concerned with and, therefore, which types of study are of most value in addressing it, with some suggestion that there is no major impact on water resources until significant changes in land use have occurred.

- Some of the agricultural land use/management practices, in particular, are dependent on very location-specific conditions, and were not regarded as replicable in other places. Other practices, whilst replicable, may not produce the same results because of different physical and climatic characteristics. Potential impacts of change may need to be considered on a case-by-case basis.

- The key message from the agriculture articles is that row crops generally use less water than pre-existing natural vegetation, the general explanation being that any bare soil reduces evaporation and the extra available water contributes to either surface runoff or groundwater recharge. One study out of seven showed the opposite impact, but this was in a semi-arid region of China so not particularly relevant to the UK.

- The key message from the other land use/management articles is that small-scale interventions to hold more water locally in the soil (e.g. tillage practices, soil treatments) are generally successful – at the local scale. This has the effect of reducing surface runoff and groundwater recharge, with the extra water being available for crops.

4.2 Assessment of process

The REA protocol is designed to be objective, repeatable and transparent, not based on pre-existing opinion and with no expectation as to the outcome. As such an REA is a systematic approach to gathering and assessing evidence, but without the depth of a systematic review.

4.2.1 The primary question

An admittedly subjective evaluation of the process suggests that the REA protocol did identify relevant and robust articles within the time and resource constraints, in order to answer the primary question "*Can land use and land management make a difference to water availability*", but that the primary question was possibly not the most appropriate question. The question contains three somewhat nebulous terms in "land use", "land management" and "water availability" which would benefit from further definition.

"Water availability" is a particularly complex term meaning different things to different people, but usually refers to a quantity of water and, as such, was expanded by also including the term "water quantity" in the REA search protocol. Water availability was taken by the REA team to mean "water potentially available for human use", which is usually water available for abstraction from rivers, lakes/reservoirs or aquifers, rather than green water (rainwater or soil moisture) and crop water use which was the focus of some original articles. An assessment of water availability in a natural environment needs to consider the variation of the water distribution in time (seasonally) and space (geographically), the accessibility of the water (whether the locations of the available water and the water demand correspond), and the associated costs of redistributing it if this is not the case), and the quality of the water.

This available water can then be exploited for use by people, for agriculture, for industry, for power generation, and for the environment. Where water availability exceeds water demands, there are no problems, but in the contrary situation it is necessary to make more water available and/or reduce the demands upon that water. Some of these issues are aspects of water management and demand management, which are not the focus of this REA review, which is concerned with whether land use and land management can affect the spatial and temporal distribution of surface water (runoff and flow) and groundwater (recharge) resources to make more water available. In this review, a systematic comparison of the different studies was hindered by the lack of a consistent and standardised experimental methodology and approach to quantifying impacts on water availability, or on the various surrogates for water availability such as runoff, flow, groundwater level, etc, and the relationships between these quantities.

4.2.2 The influence of climate change

Water availability will be changed significantly as a consequence of changes in climate. The original primary question "*Can land use and land management make a difference to water availability under conditions of climate change*" was refined during initial scoping to remove the last five words referring to climate change because it was considered too restrictive. The REA is concerned with whether land use and land management can affect the availability of water, in any circumstances. There was concern that including a climate change term in the search protocol would exclude articles that do not explicitly mention climate change but may provide useful evidence on land use and/or land management and water availability. Furthermore, it was anticipated that the majority of articles referring to climate change would be based on modelling and the REA protocol omitted inferences drawn from modelling results (for both climate and land use scenarios) from the review because models results are not primary measurements. Even though a model may have been calibrated on observed data, the model itself introduces additional uncertainty, and an associated need to compare a potentially large number of different models to understand how their structure and parameterisation may impact on results. A parallel modelling study is being conducted as part of this project by BGS and Cranfield University.

It is possible that the REA could have explored the issue of how climate change could affect land use and land management and, consequently, water availability, though a space-for-time analogy i.e. looking for evidence from locations that now experience climates similar to future projections of climates for regions of the UK (Phase 2a proposal to Defra, 2012). This would have necessitated defining the primary question to encompass the particular climatic conditions and the anticipated land use or land management intervention resulting from this climate, as well as the particular hydrological or hydrogeological impact of interest. For example, it would be possible to conduct an REA to locate and review evidence for whether changes in cropping choices of non-irrigated crops change the amount of water lost through evaporation, with the review focusing on evapotranspiration characteristics of some specific crops which may or may not become more widespread in the UK in the future as a result of climate change. Evidence from the wide geographical coverage of the final set of articles (Section 3.2.1) indicates that land use and land management can make a difference to water availability regardless of the climate of the geographical location.

4.2.3 Other issues

The value of having external input to the search process was demonstrated through the nine articles nominated by the Project Board, none of which was in the original list of 1272 titles identified using the REA search protocol. The initial scoping and subsequent application of the finalised search protocol highlighted the importance of potential search terms in the title, abstract and key words list of published articles – it is probable that several articles that may have been useful were rejected during the initial search of online databases simply because they did not include the “right” words. Whilst it might be argued that more words should have been included in this initial search space, many of the articles that did get through were subsequently rejected at the title or abstract review stages because they did not actually involve a land use or land management intervention, or were modelling studies rather than monitoring studies. Achieving a successful balance between not excluding appropriate articles whilst, at the same time, not including inappropriate ones, proved very challenging.

It was not necessary for at least two members of the team to assess every article at every stage, but this was done to provide an objective assessment of the process itself. Table 4.1 summarises the kappa scores from each stage, which measure the level of agreement between the reviewers. The scores show that the stage with the lowest score was the application of the inclusion criteria to the abstracts, where the reviewers disagreed on the status of 31 out of 125 articles, with the discrepancies resolved by discussion involving a third reviewer and sometimes brief examination of the full text to reach consensus. The issues usually involved a lack of information in the abstract to ascertain whether the inclusion criteria were met, with one reviewer being less accommodating than the other. Otherwise, the REA team considered the exclusion and inclusion criteria applied during the title and abstract review stage to be sensible and relatively easy to apply. The generally high kappa scores demonstrate that REA is a technique that can be used without everything being assessed at least twice, providing there is a well-defined protocol and good communication within the REA team.

Table 4.1: Kappa scores from application of each stage of the REA protocol

Stage	***Kappa score***
Title review -apply exclusion criteria to 1272 articles	*0.69 (good)*
Abstract review – apply inclusion criteria to 125 articles	*0.48*
Full text review – assess 59 articles	*0.76 (substantial)*
Relevance and robustness scores – assess 31 articles	*0.63 (good)*

More time and resources would also have enabled the REA team to follow up the bibliographies in the final set of 31 articles in this REA for any additional relevant references not previously identified

4.3 Recommendations

Application of the REA protocol has generated a refined source of objective evidence to address a specific question. The overarching issue being addressed is land use and land management, and their impact on water availability. The review represents a step towards a better understanding of whether there is evidence to show if and how land use and land management can affect water availability.

The evidence demonstrates that land use and land management practices can affect water fluxes, and thereby the water balance, at the field/plot scale or in headwater catchments, but does not demonstrate whether these impacts propagate downstream to affect water availability at the basin scale. Whilst the studies that are available, from a variety of locations across the world, include some interesting and useful information, they do not provide unequivocal evidence of use in determining land use and land management related impacts on water availability in a UK context.

Recommendations from this review are:

- The primary question and initial scoping to determine feasible search parameters are critical: future REAs should explicitly include stakeholder consultation from an early stage in order to better to understand the question. Focusing this review solely on UK studies would have significantly reduced the number of articles in the final set. To increase the number of UK articles, it would have been necessary to widen the search.

- Future REAs should concentrate on a particular land use or land management intervention (e.g. tillage practices, certain crops, land drainage, etc), and on a particular hydrological or hydrogeological impact, which may facilitate a broader search and, thereby, consider more articles on that topic, or at a particular geographical location, within the time frame of the review.

- In order to generate a larger body of UK-specific evidence, there is a need for coordinated, targeted research and long-term monitoring to investigate the water-related impacts from the most important land uses and land management interventions, across a variety of catchment types.

- There is a need to consider the impacts of land use and land management on water quality, as well as on water quantity.

4.4 Postscript

Existing knowledge and understanding about the effect of land use and land management on water resources have probably been developed over many years. However, the review identified what the REA team regarded as an unexpectedly small volume of peer-reviewed literature on the topic, with relatively little specific detail on quantitative impacts. Thus, it can only be assumed that much of the knowledge has come from grey literature, unpublished studies, or pre-conceptions, which were, for the most part, not assessed as part of this review.

The strength of the opinion that certain land use or land management interventions do have an impact of water availability was demonstrated by many of the comments made at a stakeholder workshop hosted by Defra on 1 July 2013. It emerged that little, if any, evidence existed to support many of the opinions expressed and that opportunities to gather supporting data as part of active or planned interventions are often missed.

This leads to some reflection and speculation of the circumstances under which such an REA or other systematic review of evidence can actually change widely-held opinions, where no evidence justifying those opinions is shown to exist. For this particular issue, the divergence between opinion and REA findings may be at least partly explained by the fact that while local interventions can modify local water regimes (for which evidence was found in this review), such interventions are not shown to make more water available as a resource on a larger scale. This reiterates the importance of the primary question which defines the boundaries of the REA.

5. References

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Proposal to Defra. 2012. Land use, climate change and water availability: Phase 2a. British Geological Survey, Cranfield University and Centre for Ecology & Hydrology, UK.

Appendix 1 Final list of articles

Aarts, H. F. M., B. Habekotte and H. van Keulen (2000). "Ground water recharge through optimized intensive dairy farms." Journal of Environmental Quality 29(3): 738-743. (Agriculture)

Davis, E. A. (1993). "Chaparral control in mosaic pattern increased streamflow and mitigated nitrate loss in Arizona." Water Resources Bulletin 29(3): 391-399. (Land management)

Deeks, L. K., M. A. Clarke, I. P. Holman, N. J. K. Howden, R. J. A. Jones, T. R. E. Thompson and I. G. Truckell (2008). "What effect does soil compaction in grassland landscapes have on rainfall infiltration and runoff?" SEESOIL 17: 11. (Land management)

DeLaune, P. B. and J. W. Sij (2012). "Impact of tillage on runoff in long term no-till wheat systems." Soil & Tillage Research 124: 32-35. (Land management)

Dung, B. X., T. Gomi, S. Miyata, R. C. Sidle, K. Kosugi and Y. Onda (2012). "Runoff responses to forest thinning at plot and catchment scales in a headwater catchment draining Japanese cypress forest." Journal of Hydrology 444: 51-62. (Forestry)

Fernandez, C., J. A. Vega, J. M. Gras and T. Fonturbel (2006). "Changes in water yield after a sequence of perturbations and forest management practices in an Eucalyptus globulus Labill. watershed in Northern Spain." Forest Ecology and Management 234(1-3): 275-281. (Forestry)

Finch, J. W. and A. B. Riche (2008). "Soil water deficits and evaporation rates associated with Miscanthus in England." Aspects of Applied Biology 90: 8. (Biofuels)

Finch, J. W., R. L. Hall, P. T. W. Rosier, D. B. Clark, C. Stratford, H. N. Davies, T. J. Marsh, J. M. Roberts, A. Riche and D. Christian (2004). "The hydrological impacts of energy crop production in the UK Final report." Department of Trade & Industry, London. (Biofuels)

Giertz, S., B. Junge and B. Diekkruger (2005). "Assessing the effects of land use change on soil physical properties and hydrological processes in the sub-humid tropical environment of West Africa." Physics and Chemistry of the Earth 30(8-10): 485-496. (Land management)

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Huang, T., Z. Pang and W. M. Edmunds (2013). "Soil profile evolution following land-use change: implications for groundwater quantity and quality." Hydrological Processes 27(8): 1238-1252. (Agriculture)

Leblanc, M. J., G. Favreau, S. Massuel, S. O. Tweed, M. Loireau and B. Cappelaere (2008). "Land clearance and hydrological change in the Sahel: SW Niger." Global and Planetary Change 61(3-4): 135-150. (Agriculture)

Lozano-García, B., L. Parras-Alcántara and M. del Toro Carrillo de Albornoz (2011). "Effects of oil mill wastes on surface soil properties, runoff and soil losses in traditional olive groves in southern Spain." Catena 85(3): 187-193. (Land management)

Marc, V. and M. Robinson (2007). "The long-term water balance (1972-2004) of upland forestry and grassland at Plynlimon, mid-Wales." Hydrology and Earth System Sciences 11(1): 44-60. (Forestry)

Martínez, F., M. A. Casermeiro, D. Morales, G. Cuevas and I. Walter (2003). "Effects on run-off water quantity and quality of urban organic wastes applied in a degraded semi-arid ecosystem." Science of the Total Environment 305(1-3): 13-21. (Land management)

Narain, P., R. K. Singh, N. S. Sindhwal and P. Joshie (1998). "Water balance and water use efficiency of different land uses in western Himalayan valley region." Agricultural Water Management 37(3): 225-240. (Forestry)

O'Connell, P. E., K. J. Beven, J. N. Carney, R. O. Clements, J. Ewen, H. Fowler, G. L. Harris, J. Hollis, G. M. O'Donnell, J. C. Packman, A. Parkin, P. F. Quinn, S. C. Rose, M. Shepherd and S. Tellier (2004). "Review of impacts of rural land management on flood generation: Impact study report." Defra R&D Technical Report FD2114/TR. (Agriculture)

Prevost, M., A. P. Plamondon and P. Belleau (1999). "Effects of drainage of a forested peatland on water quality and quantity." Journal of Hydrology 214(1-4): 130-143. (Land management)

Raymond, P. A., N.-H. Oh, R. E. Turner and W. Broussard (2008). "Anthropogenically enhanced fluxes of water and carbon from the Mississippi River." Nature 451(7177): 449-452. (Agriculture)

Robinson, M., A. L. Cognard-Plancq, C. Cosandey, J. David, P. Durand, H. W. Fuhrer, R. Hall, M. O. Hendriques, V. Marc, R. McCarthy, M. McDonnell, C. Martin, T. Nisbet, P. O'Dea, M. Rodgers and A. Zollner (2003). "Studies of the impact of forests on peak flows and baseflows: a European perspective." Forest Ecology and Management 186(1-3): 85-97. (Forestry)

Ruprecht, J. K. and N. J. Schofield (1991). "Effects of partial deforestation on hydrology and salinity in high salt storage landscapes. I. Extensive block clearing." Journal of Hydrology 129(1-4): 19-38. (Forestry)

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Scanlon, B. R., R. C. Reedy, D. A. Stonestrom, D. E. Prudic and K. F. Dennehy (2005). "Impact of land use and land cover change on groundwater recharge and quality in the southwestern US." Global Change Biology 11(10): 1577-1593. (Agriculture)

Scott, D. F. and F. W. Prinsloo (2008). "Longer-term effects of pine and eucalypt plantations on streamflow." Water Resources Research 44. (Forestry)

Sharda, V. N., P. Samraj, S. Chinnamani and V. Lakshmanan (1988). "Hydrological behaviour of the Nilgiri sub-watersheds as affected by bluegum plantations, part II. Monthly water balances at different rainfall and runoff probabilities." Journal of Hydrology 103(3-4): 347-355. (Forestry)

Sikka, A. K., J. S. Samra, V. N. Sharda, P. Samraj and V. Lakshmanan (2003). "Low flow and high flow responses to converting natural grassland into bluegum (Eucalyptus globulus) in Nilgiris watersheds of South India." Journal of Hydrology 270(1-2): 12-26. (Forestry)

Stewart, M. K. and B. D. Fahey (2010). "Runoff generating processes in adjacent tussock grassland and pine plantation catchments as indicated by mean transit time estimation using tritium." Hydrology and Earth System Sciences 14(6): 1021-1032. (Forestry)

Stone, K. C., P. G. Hunt, K. B. Cantrell and K. S. Ro (2010). "The potential impacts of biomass feedstock production on water resource availability." Bioresource Technology 101(6): 2014-2025. (Forestry)

Temesgen, M., H. H. G. Savenije, J. Rockström and W. B. Hoogmoed (2012). "Assessment of strip tillage systems for maize production in semi-arid Ethiopia: Effects on grain yield, water balance and water productivity." Physics and Chemistry of the Earth 47-48: 156-165. (Land management)

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Appendix 2 Relevance and robustness scoring for final list of articles

Agriculture

Study	Relevance					Robustness				
	Location	Scale	Subject	Inter-vention	Overall	Objective	Approach	Evaluation	Reporting	Overall
Aarts et al (2000)	2	2	3	2	**9**	3	1	2	3	**9**
Huang et al. (2013)	1	2	3	3	**9**	3	3	2	3	**11**
Leblanc et al (2008)	1	3	2	3	**9**	3	2	3	3	**11**
O'Connell et al (2004)	3	3	1	2	**9**	1	1	1	2	**5**
Raymond et al (2008)	2	3	3	1	**9**	2	3	2	3	**10**
Scanlon et al (2007)	2	3	2	2	**9**	1	2	2	3	**8**
Scanlon et al (2005)	1	2	3	3	**9**	3	2	3	3	**11**
Average score					**9**					**9.3**

Biofuels

Study	Relevance					Robustness				
	Location	Scale	Subject	Inter-vention	Overall	Objective	Approach	Evaluation	Reporting	Overall
Finch & Riche (2008)	3	1	2	3	**9**	2	1	3	3	**9**
Finch et al (2004)	3	2	2	3	**10**	2	2	3	2	**9**
Average score					**9.5**					**9**

Forestry

Study	Relevance					Robustness				
	Location	Scale	Subject	Inter-vention	Overall	Objective	Approach	Evaluation	Reporting	Overall
Dung et al (2012)	1	3	3	3	**10**	3	3	3	3	**12**
Fernandez et al (2006)	1	3	2	3	**9**	3	2	3	3	**11**
Marc & Robinson (2007)	3	3	3	3	**12**	3	3	3	3	**12**
Narain et al (1998)	1	2	1	3	**7**	2	3	2	3	**10**
Robinson et al (2003)	2	3	3	3	**11**	3	3	3	3	**12**
Ruprecht & Schofield (1991)	1	3	3	3	**10**	3	3	3	3	**12**
Scott & Prinsloo (2008)	2	3	3	3	**11**	3	3	3	3	**12**
Sharda et al (1988)	1	3	3	3	**10**	3	3	2	3	**11**
Sikka et al (2003)	1	3	3	3	**10**	3	3	3	3	**12**

Stewart & Fahey (2010)	2	3	3	3	**11**	3	3	3	3	**12**
Stone et al (2010)	2	3	1	1	**7**	1	1	1	3	**6**
Whitehead & Robinson (1993)	3	3	2	3	**11**	2	1	1	3	**7**
Average score					**9.9**					**10.8**

Land management

Study	**Relevance**					**Robustness**				
	Location	**Scale**	**Subject**	**Inter-vention**	**Overall**	**Objective**	**Approach**	**Evaluation**	**Reporting**	**Overall**
Davis (1993)	2	3	3	3	**11**	3	3	3	3	**12**
Deeks et al (2008)	3	1	3	3	**10**	3	2	3	2	**10**
DeLaune & Sij (2012)	1	1	2	3	**7**	2	2	1	3	**8**
Giertz et al (2005)	1	3	3	3	**10**	3	3	3	3	**12**
Gregory et al (2005)	2	1	3	3	**9**	2	2	2	3	**9**
Holman et al (2002)	3	2	1	3	**9**	3	1	1	2	**7**
Lozano-Garcia et al (2011)	2	1	3	3	**9**	2	3	3	3	**11**
Martínez et al (2003)	1	2	2	3	**8**	3	3	2	3	**11**
Prevost et al (1999)	2	3	3	3	**11**	3	3	3	3	**12**
Temesgen et al (2012)	1	1	3	1	**6**	2	3	3	3	**11**
Average score					**9**					**10.3**

Appendix 3 Summary information for final list of articles

Agriculture

Study	Subject and intervention	Evaluation methodology	Results	Conclusions and recommendations	Relevance & Robustness	Comments
Aarts et al (2000)	Study location is De Marke experimental farm, Netherlands, employing a prototype farming system to increase extractable groundwater quantity for human use without reducing milk production or exporting slurry. Land use is permanent grassland and 2 areas of crop rotation (maize and ryegrass on 3 and 5-year cycles) that are sprinkler-irrigated from groundwater.	Detailed monitoring and management of water use to maximise groundwater production by restricting ET e.g. crops are irrigated only to prevent death, not to stimulate growth. Non-formal comparisons are made with a hypothetical farm based on literature, observation and stakeholder consultation.	De Marke farm uses 15% (207 m^3 ha^{-1} y^{-1}) less irrigation water than the hypothetical reference farm, partly a result of growing a higher proportion of maize (grassland irrigation demand being higher than for maize). This reduced crop water consumption increases recharge by 550 m^3 ha^{-1} y^{-1}.	The study offers some potential for improving groundwater management in intensive dairy farms on sandy soils susceptible to leaching. However, it is difficult to replicate elsewhere and transfer to other situations because of the location-specific conditions.	Relevance: 9 Robustness: 9	This experimental farm is on a sandy soil with a tightly coupled aquifer system and the focus of the paper is really water management. Results demonstrate that, under strict management of nutrients and irrigation, it is possible to “generate” more water for human use and that, overall, this is economically worthwhile.
Huang et al (2013)	Field studies investigating impact on groundwater recharge of converting natural vegetation to rain-fed agriculture in semi-arid Hequan terrace, Guyan, Ningxia Province, in the central Loess Plateau of China. 90% of land converted to winter wheat 100 years ago, and rest to alfalfa 30 years ago.	Variety of monitoring approaches used to provide data on groundwater recharge rates, ages and mechanisms and the time lag between potential recharge and actual recharge, including deep soil profiles and multiple tracers. Control is 2 sites of natural shallow-rooted grassland undisturbed for 100+ years.	In control plots, recharge is 94-100 mm y^{-1} and it takes decades or more for precipitation to pass through the unsaturated zone. Converting to winter wheat decreases recharge to 50-55 mm y^{-1}; converting from winter wheat to alfalfa decreases recharge to almost 0.	The impacts of land use change on recharge take a long time to become apparent, and it may be many more years before a new steady-state is achieved.	Relevance: 9 Robustness: 11	The Loess Plateau of China is not like other semi-arid areas, so the results and conclusion are not widely applicable. However, the study doesn’t make any statement as to the implications of the changes in recharge e.g. extra water sustaining river flows or being available for abstraction.
Leblanc et al (2008)	Catchment/basin-	Before/after study with	Increase in surface	As the rate of land		

	scale studies exploring runoff and recharge changes associated with clearance of 80% of natural vegetation for agriculture and fuel (associated with large population increase) in a 500 km^2 rural area of the central Sahel in southwest Niger, West Africa.	time horizons 1950, 1960, 1975 and 1992. Hydrological and hydrogeological data from Hapex-Sahel and AMMA projects. Observations of land cover and hydrological changes using a time series of aerial photos supplemented by some ancillary GIS data and field surveys.	water, associated with 157% increase in drainage density explained by increase in Hortonian runoff following land clearance, decrease in vegetation cover and soil crusting. Also widespread, steady rise of water table (~4m between 1963-2001, particularly since 1980s), implying a significant increase in recharge; 30-year time lag between land clearance and water table rise suggests recharge is associated with timing of drainage network connectivity.	clearance increased over the past century, the main hydrological effects may not yet be fully detectable. Diagnosing changes in water resources for semi-arid areas can be based on the determination of key hydrological variables (drainage density, connectivity) and land cover from remote sensing data, often acquired on a more systematic and larger scale than in-situ hydrological data.	Relevance: 9 Robustness: 11	Major hydrological changes result from this dramatic change in land use. Felling trees makes more water available to both surface water and groundwater.
O'Connell et al (2004)	Review report considering the impacts of land use and land management on flooding, at all scales, primarily in the UK.	Review of existing evidence.	There is substantial evidence that land use and land management practices affect runoff generation at the local scale. There is only very limited evidence that these effects are transferred to the surface water network and propagated downstream.	Rainfall-runoff modelling to predict impacts of land use and land management is in its infancy. A considerable amount of high quality field data on impacts will be needed to support the development of robust methods for predicting impacts.	Relevance: 9 Robustness: 5	These articles are about impacts on flood/flow generation rather than on water availability. Some of the issues raised are relevant to water availability.
Raymond et al (2008)	Subcatchment studies exploring relationship between percentage cropland and change in discharge in Mississippi basin, USA.	The change in discharge at average precipitation (calculated by averaging the time periods <1966 and >1987) is plotted against percentage cropland for	There is a lot of scatter but the change in discharge increases from around 0 change at 0% cropland to around 0.04m yr^{-1} at 90% cropland. This increase in discharge (equivalent to ~50 km^3	Land use and land management changes are more important than changes in climate. Potential agricultural practices that might be causing the reported increase in discharge are "tile	Relevance: 9 Robustness: 10	

		subcatchments of the Mississippi.	yr^{-1} for the Mississippi) is not balanced by a rise in precipitation.	drainage, fertilizer use, irrigation, tillage practices and changes in crop type, rotation and productivity."		
Scanlon et al (2007)	Review paper considering the global impacts on water resources, at a variety of scales, resulting from conversions from natural to agricultural ecosystems.	Review of existing evidence.	Converting from natural vegetation to forest increases ET by 60%. Converting from Eucalyptus to rain-fed agriculture decreases ET by 10% and increases downward flux of water by a factor of 1-2. Replacing natural vegetation with rain-fed agriculture may increase recharge due to bare soils in fallow periods and soil crusting generating focused recharge zones. Limited data suggest that replacing Eucalyptus with annual crops can also lead to increase in groundwater levels of ~1 m y^{-1} in areas of shallow aquifers.	Impacts of land use changes on water resources can have opposing effects on quantity and quality of available water. Converting from natural vegetation to rain-fed agriculture usually increases water quantity but decreases water quality; converting to irrigated agriculture decreases both water quantity and quality. However, impacts of changes in vegetation may not be realised for 10s to 100s of years, and some interventions can have pronounced seasonal effects.	Relevance: 9 Robustness: 8	Two very different papers by Scanlon, but both considering both the quantity and quality of available water. The 2007 paper tries to draw some general conclusions about the impacts on water resources of land use change from previous studies from around the world, whilst the 2005 paper focuses on the impacts on groundwater in the southwest USA and includes some information about irrigation which is not relevant to this REA.
Scanlon et al (2005)	Field studies investigating impact on groundwater recharge of converting natural rangeland (arid/semi-arid, uncultivated grassland and shrub) to agriculture (irrigated or dryland/rain-fed/cattle-grazing) in the Amargosa Desert	Variety of monitoring approaches used to provide data on groundwater fluxes and system response to land use and land cover change (and to climate change), including unsaturated and saturated zone profiles, time series of matric potentials, and	In natural rangelands, recharge is negligible due to ET. Converting from rangelands to dry-land agriculture increases recharge – in HP moderate recharge of 9-32 mm y^{-1} reported; converting to irrigated agriculture increases recharge further – in	Converting from natural vegetation to dryland agriculture changes water fluxes from upward discharge (ET) to downward recharge, but at the expense of natural rangeland species. Good correspondence between recharge	Relevance: 9 Robustness: 11	

	(AD), Nevada, USA and at 3 sites in High Plains (HP), Texas, USA.	groundwater chemistry data. 2 rangeland control sites in HP field area.	AD moderate-high recharge of 130-640 mm y^{-1} reported.	estimates from different approaches increases confidence in the results.		

Biofuels

Study	Subject and intervention	Evaluation methodology	Results	Conclusions and recommendations	Relevance & Robustness	Comments
Finch & Riche (2008)	Field studies investigating impact of *Miscanthus* crops on soil water and energy fluxes at 4 locations (Richards Castle, Rothamsted, Woburn, Watchet) in England, UK	Detailed monitoring of water and energy fluxes in 4 plot/field scale sites. Data are compared with reference values from literature to assess differences in water use between *Miscanthus* and other crops.	At all sites, minimum soil water content occurred between mid Sep and mid Oct, reflecting the seasonal balance between rainfall rates and evaporation rates. Low evaporation rates in Sep are interpreted as evidence of transpiration being limited by soil water availability.	For the same soils and climate, soil water under *Miscanthus* is depleted to depths greater than the rooting depths of UK arable crops. *Miscanthus* transpires less than grass, maize and winter wheat, but interception losses are higher.	Relevance: 9 Robustness: 9	These articles present much of the same evidence. The focus is about how the different biofuel crops use water, not about water availability. Hence, the impact of biofuel crops on water resources requires further work to consider water losses due to interception, as well as transpiration.
Finch et al (2004)	Field studies investigating impact of *Miscanthus* and Switchgrass crops and Poplar and Willow Short Rotation Coppice (SRC) on soil water and energy fluxes at 4 locations (Richards Castle, Rothamsted, Roves Farm, Woburn) in England, UK	Detailed monitoring of water and energy fluxes in 3 plot/field scale sites under 3 vegetation types, plus some data from an earlier study for a fourth vegetation type. Data are used to parameterise a MOSES model, run to assess the differences in water use between these and existing land uses.	For the 8 cells in the MOSES model, *Miscanthus* and switchgrass both used less water than the existing land use in every case. Poplar SRC used more water in every case. Willow SRC water use was generally the same as the existing land use.	For same soils and climate, water use of energy grasses is less than/equal to existing grass or tilled land cover, but less than for woodland or heathland. Poplar SRC water use is very high, regardless of existing land cover. Interception and transpiration are both important factors influencing water use.	Relevance: 10 Robustness: 9	

Forestry

Study	Subject and intervention	Evaluation methodology	Results	Conclusions and recommendations	Relevance & Robustness	Comments
Dung et al (2012)	Paired headwater catchment study in Central Mie Prefecture, south-central Japan, to assess impact on runoff of thinning Japanese cypress forest planted in early 1960s. Catchments have areas 0.18 ha and 0.35 ha.	Streamflows monitored using Parshall flumes. Precipitation, plot runoff and catchment runoff data collected at 5-min intervals. Monitoring over pre-treatment (Jun 2004-07) and post-treatment (Mar 2007-Jun 2009) periods.	Forest thinning increases annual runoff by 240.7mm, and increases flow duration in an ephemeral channel from 56.7% to 73.3%. Increases in runoff are associated with increases in baseflow, rather than overland flow; increases are related to changes in precipitation, ET and soil water availability.	Post-thinning increases in runoff are less than increases in runoff after partial harvesting of subcatchments. Effect of thinning is strongly dependent on observation scale, with runoff expected to revert to original level within 5 years as baseflow reverts to original quantity.	Relevance: 10 Robustness: 12	The paper includes an appendix table summarising results of previous studies for effect of various forest treatments on runoff (note that the source papers for the studies have not been read).
Fernandez et al (2006)	Paired catchment study near Pontevedra, Spain to assess impact on runoff of wildfire-clearfelling-coppice sprout selection-foliar damage sequence in *Eucalyptus globulus* Labill. forest. Catchments have areas 9.9 ha (Castrove, treated catchment) and 6.7 ha (Caldas, control with *Pinas pinaster* Ait.).	Streamflows continuously measured at the outlet of the catchments using 90^{O} V-notch weirs. Mean precipitation obtained from a network of raingauges in each watershed. Monitoring 1987-2005.	The interventions each cause increases in mean annual streamflow over the subsequent 3 years: wildfire of 68%, clearfelling 73%, coppice sprout selection 47% and foliar damage 22%. There is no evidence of a cumulative effect. 70% of the increases are explained by differences in annual rainfall.	Rainfall and its seasonality control most of the increase in streamflow. Increases are most pronounced in Autumn and Winter; in no cases is an increase in water availability observed in Summer. The results may have implications for forest management practices.	Relevance: 9 Robustness: 11	The focus of the paper is the hydrological response to a sequence of frequent (3-yearly) interventions, but whilst the authors state that there is no evidence of a cumulative effect this was not tested by having additional control areas.
Marc & Robinson (2007)	Paired headwater catchment study at Plynlimon, central Wales, UK, to assess impacts of upland forestry (forest age, commercial felling, regrowth) and update the water balance.	Monitoring since 1971. Streamflows monitored using steep stream flumes. Catchment rainfall estimated from a network of 48 monthly-read storage raingauges, reduced	Mean annual figures over 1972-2004 period: catchment precipitation 2600 mm Wye, 2555 mm Severn; runoff 2111 mm Wye, 1987 mm Severn; losses (P-Q) 488mm Wye, 566 mm	Evaporation losses from forests are greater than those from grasslands, but some evidence of systematic age-related decline in forest evaporation losses. Felling	Relevance: 12 Robustness: 12	This was the highest scoring paper from the REA for relevance and robustness (though 9 others also

	Catchments have areas 1055 ha (Wye, grassland control) and 870 ha (Severn, 70% managed conifer forest).	to 21 in 1999. 2 AWS in each catchment, plus 2 manual met stations (1 in Severn and 1 5km outside) used to estimate ET.	Severn. In 70% forested Severn, tree water use fell from 250 mm y^{-1} to 150 mm y^{-1} due to increasing forest age.	reduces evaporation losses and increases baseflows: low flows are augmented but no detectable changes in peak flows.		scored top marks for the latter category).
Narain et al (1998)	Field studies investigating impact of various tree/crop mixtures (*Leucaena*, Eucalyptus, maize-wheat, *Chrysopogon* grass, turmeric) on 9 15m x 90m plots on a 4° slope at the Central Soil & Water Conservation Research Farm, Dehradun, Western Himalayas, India.	Hydrometeorological data were collected from the plots over a 9-year period (1983-92) and used to calculate runoff, water use and water use efficiency. Different land use treatments were applied to each plot, with both summer and winter crops.	Afforestation with fast-growing tree species on agricultural land substantially reduces catchment runoff and GW recharge to near 0. Water use by sole tree plantations > trees > trees+grass > trees+crops > crops >cultivated fallow land. The effect is ascribed to the greater interception by, and infiltration under trees.	In winter, water use (evapotranspiration) is limited by evaporative demand. In summer, water use is limited by water availability which varies with soil depth, such that agro-forestry combinations have greater water use efficiency than mono-crop systems.	Relevance: 7 Robustness: 10	The article only considers water availability within the plots. There is no evidence for whether the reported effects are also observed at the catchment scale.
Robinson et al (2003)	A series of paired catchment studies across Europe to assess impacts of forests on peak flows and baseflows. The 28 small study basins were located on two transects along climatic gradients: (a) Oceanic to Continental, and (b) Mediterranean to cool Temperate, and encompassed a wide range of forest types (conifers in NW Europe, broadleaf in central Europe, eucalyptus in SE Europe), climates and ground conditions.	In each case, flow changes of the forest basin over time are compared with those of benchmark or control basin to remove the influence of climatic variability. Studies cover whole forest life cycle: site preparation, planting, young, mature, felling, and post-felling.	In conifer forestry, pre-planting drainage decreases runoff response times and increases peak and baseflows for up to 10 years; for mature trees, peaks are similar to unforested (continued tree growth and associated drain infill leads to decrease in peak flows over time); felling increases peak and baseflows but impacts not detectable at larger catchment scale. In broadleaf woods, there is a relatively small and/or short-lived difference in	Results revealed broad consistency between regions and sites. At the local scale, there are specific situations where forest impacts are potentially significant to peak flows and low flows, but at the regional or EU scale, forestry has a relatively small impact on extreme flows where forest management is phased across a basin or only a part of a basin is forested. Geology and soils can mask the impact of differences in	Relevance: 11 Robustness: 12	Study is output from EU FOREX (FORestry and EXtreme flows) project (FAIR-0235). Interesting to get an EU-wide comparison and assessment.

	Approximately 80% commercially managed forest.		peak flows or baseflows from unforested. In eucalyptus plantations, coppicing increases peak and baseflows for 1-2 years.	vegetation cover. Forestry drainage channels or furrows can augment baseflows by providing a deeper outlet for soil profile gravity drainage.		
Ruprecht & Schofield (1991)	Paired headwater subcatchment study in 300ha Dons catchment, Eastern Collie Basin, Western Australia, to assess impact on groundwater levels of 3 different eucalyptus forest clearing strategies (strip clearing in subcatchments I and II, soil clearing in subcatchments III and IV and parkland clearing in subcatchment V).	Streamflow measured at a sharp crested V-notch weir. Rainfall continuously measured at a site just outside Dons catchment. Groundwater levels monitored on a 1-3 monthly basis for each treatment - though 70% of pieziometers remained dry, meaning results were dependent on 1-2 pieziometers only. Monitoring 1977-89.	Over 1974-89 period, 60-70% cleared subcatchments show 7.8-10.2m rise in groundwater levels; 32% cleared subcatchments show 5.8m rise in levels; native forest control shows 2.3 m fall in levels (i.e. 0.2 m y^{-1}). 13 mm increase in mean annual runoff. Rate of rise under strip clearing gradually accelerating, whilst under parkland clearing gradually declining (in response to increasing leaf area of the crown).	Groundwater levels have risen substantially (6-10m) in response to a range of vegetation treatments involving replacing 32-90% of native forest with pasture. Responses are dominated by the vegetation treatment in terms of magnitude, distribution and type, but some of the results may be very specific to catchment geology.	Relevance: 10 Robustness: 12	Although the streamflow impacts are the combined result of multiple interventions, so difficult to apportion, the groundwater level impacts are monitored for each intervention.
Scott & Prinsloo (2008)	2 paired catchment studies in South Africa to assess impact on runoff of afforestation. At Jonkershoek Forestry Research Station, Tierkloof catchment (157.2 ha) is 36% forested with *Pinus radiata*, whilst Langrivier (245.8 ha) is not. At Westfalia, Westfalia-D (39.6 ha) is 100% with	Streamflows gauged with sharp-crested 90°V notch weirs surmounted with 1.83 m wide rectangular notches. Stage heights monitored continuously. Rainfall measured using recording raingauges. Digitised streamflow and rainfall records summed by month. Monitoring 1942-2003	*Pinus radiata* took 6 years to significantly reduce streamflows, with average peak reductions of 44 mm (7.7%) a^{-1} per 10% of catchment planted when the trees were between 10-20 years old. After 30 years, flows tend to pre-planting levels; by 40 years, no significant statistical difference.	In both cases, planting leads to large reductions in streamflow, which lessen with the age of the trees. High levels of streamflow reduction are not sustained after the trees reach maturity and streamflows recover by the end of long rotations - in these cases 20 and	Relevance: 11 Robustness: 12	Interesting to see long-term effects at Jonkershoek. Authors consider other possible benefits of increased rotation

	Eucalyptus grandis, whilst Westfalia-B (32.6 ha) is not.	Jonkershoek and 1983-2003 Westfalia.	Faster growing *Eucalyptus grandis* reached peak water use between 6-14 years after planting, with average peak reductions of 40 mm (10%) a^{-1} per 10% of catchment planted. After 15-20 years, flows return to 50% of pre-planting flows.	40 years for eucalypts and pines, respectively, which are greater than typical commercial rotations. Hence, reductions in water resources may be mitigated by increasing rotation lengths.		lengths such as restoring degraded catchments and storing carbon.
Sharda et al (1988)	Paired headwater catchment study at Glenmorgan Research Farm, Ootacamund, Nilgiris, Tamil Nadu, India, to assess impact on runoff of bluegum (*Eucalyptus globulus*). Catchments have areas 33.2 ha (A) and 31.9 ha (B, planted with 18.8 ha bluegum in 1972).	Hydrometeorological data were collected from the catchments from 1968. Both catchments kept under natural conditions (grassland and savannah) 1968-71, before bluegum planting in B. Bluegum rotation consists of coppicing the trees after 10, 20 and 30 years and final felling and replanting after 40 years.	In the first 10 years after planting, bluegum causes a 10% reduction in water yield, in both total flow and baseflow. The maximum reduction occurs during July-November, August being the month of highest flow. The reduction is less during January-April, March being the month of lowest flow, with a reduction in water yield of 23% (with 50% probability of occurrence).	The least amount of water is available during March, which is the most crucial period for the hydropower reservoirs. This would need to be considered before converting natural grassland to large-scale bluegum plantations.	Relevance: 10 Robustness: 11	These present an interesting pair of papers, using the same Indian example but with a gap of some 15 years. The first includes more basic data analysis and the second more analysis of the monitoring results, though the outcomes and conclusions are essentially the same.
Sikka et al (2003)	Paired headwater catchment study at Glenmorgan Research Farm, Ootacamund, Nilgiris, Tamil Nadu, India, to assess impact on runoff of bluegum (*Eucalyptus globulus*). Catchments have areas 33.2 ha (A) and	Hydrometeorological data were collected from the catchments from 1968. Both catchments kept under natural conditions (grassland and savannah) 1968-71, before bluegum planting in B. Focus on analysis in this	Conversion of natural grassland to bluegum results in decreased baseflows and peak flows and increased soil moisture losses, with effects more pronounced during the second rotation (first coppiced growth) than the first rotation. A	The second rotation of bluegum had greater hydrological effect than the first rotation. The adoption of appropriate silvicultural practices (e.g. planting fast growing tree species at wider spacing, following different	Relevance: 10 Robustness: 12	

	31.9 ha (B, planted with 18.8 ha bluegum in 1972).	paper was differences in low flows and high flows between the two catchments.	low flow index (LFI) decreased by x2 and x3.75 for the first and second rotations, respectively, with March, the lowest flow month, most affected. Effect of forestry on peak flows becomes less significant at higher return periods.	rotation periods, having mixed plantations) can help to mitigate adverse impacts of bluegum forestry, particularly in catchments with hydropower dams potentially affected by low flows.		
Stewart & Fahey (2010)	Paired catchment study at Glendhu, central Otago, new Zealand, to assess impact on runoff of afforestation with *Pinus radiata* of a tussock grassland catchment. Catchments have areas 310 ha (afforested) and 218 ha (control).	Hydrometeorological data were collected from the catchments since 1980. Both catchments kept under natural conditions 1980-82, *Pinus* planting. Study uses tritium to estimate transit time of water flowing from 2 catchments.	Change in ET from 600 mm y^{-1} for grassland to 860 mm y^{-1} for forest results in equivalent reduction in runoff. Dating showed that much of baseflow component was "old" water from deep aquifers, less affected (to date) by change in land use than shallow aquifers.	In addition to already observed changes in water balance there may be other changes that may not become apparent for decades as deep aquifers potentially respond to afforestation. The impacts of land use change may take a long time to become apparent.	Relevance: 11 Robustness: 12	Main focus of paper is apportionment of baseflow to deep and shallow aquifers and associated transit times but it it makes some references to impact of different land treatments.
Stone et al (2010)	Review paper considering the issues around biomass feedstock production in the USA, but also including references about the impacts of afforestation.	Review of existing evidence.	Evidence cited includes forest plantation decreasing annual streamflow by 53%, and conversion from grassland to pine plantation increasing ET by 40-70%.	All aspects of water requirements and water resources should be considered in biofuel production, including water use of tree plantations.	Relevance: 7 Robustness: 6	This paper is categorised as forestry (rather than biofuels) because it refers to forestry studies – amidst a lot of information not so relevant to this REA.
Whitehead & Robinson (1993)	Review paper including what the authors consider the most influential experiments on afforestation and deforestation.	Review of existing evidence. Paper refers to Bosch & Hewlett (1982) review of 94 studies on impact of forest on water yield, and extends it with some additional studies, including Plynlimon.	The paper focuses on 9 specific studies for which it shows the direction of change in streamflow in Table 1 of the paper (note that the source papers for the studies have not been read).	There is agreement as to the direction of change for the 5 deforestation studies (decrease in annual, peak and base flows), but no agreement for the 2 afforestation studies or 2 comparison studies.	Relevance: 11 Robustness: 7	It is interesting that the Bosch & Hewlett (1982) paper was not in the initial list of 1272 articles generated by the REA protocol.

Land management

Study	Subject and intervention	Evaluation methodology	Results	Conclusions and recommendations	Relevance & Robustness	Comments
Davis (1993)	Paired catchment study exploring impact on runoff and water quality of mosaic treating Whitespar chaparral (scrub) watersheds, central Arizona, USA, with herbicide pellets to control heavy water-using chaparral and increase discharge without degrading the resource.	Rainfall and runoff were measured from two catchments, one mosaic treated with tebuthiuron herbicide (over 55% of 302.9 acres total area) and the treated area replaced with grass, and one untreated (246.5 acres). Date collected for 9 years pre-treatment and 7 years post-treatment.	Pre-treatment data indicate very similar rainfall and runoff on the two catchments, with a lot of year-to-year variability. Treatment increases runoff by a factor of 2 compared to the control (16% v 8%), except for years with very low rainfall where there is no significant difference.	This intervention was seen as an effective intervention to increase runoff and did not have adverse water quality impacts (increased nitrate levels attributed to the treatment were diluted upon reaching the watershed outlet).	Relevance: 11 Robustness: 12	There is no evidence for whether the observed changes would be sustained and whether they are also seen at the basin scale.
Deeks et al (2008)	Field studies investigating impact on runoff of 3 land management practices (intensive grazing ley pasture, intensive grazing ley pasture over stony soil, extensive grazing permanent pasture) at 3 grassland sites with the same soil type and used for dairy/ livestock grazing in Cornwall, UK.	Using a rainfall simulator, rainfall and runoff data were measured and compared with results of a desk-based study to assess the potential hydrological impact of grassland soil compaction across the UK using catchment average values of standard percentage runoff (SPR) and baseflow index (BFI) based on the 1:250K National Soil Map of England & Wales.	Field studies revealed large increases in runoff from 12-41%. Desk study showed changes in catchment SPR as a result of soil compaction are less than 6% (although some catchments, in the southwest, showed indicative increases of 13-41%) and changes in catchment BFI are less than 8%.	Large increases in runoff in field studies can become only small changes in SPR and BFI at the catchment scale. In the field studies, the soil compaction and surface runoff were positively related to both intensity of land use and duration of intensive grazing, and may have contributed to soil erosion and flood events observed in the catchment.	Relevance: 10 Robustness: 10	Whilst attempts are made to assess the field study results in a wider context, further validation is required to assess how representative these values are of catchment scale responses.
DeLaune & Sij (2012)	Field studies investigating impact of 7 different tillage practices (no-till, till and 5 types of aeration) on wheat systems in Texas Rolling Plains Region,	Rainfall and runoff data were measured and compared. One rainfall simulation experiment was conducted 3 months into the tillage regimes. Runoff was	The 5 types of aeration had no discernable benefits after 3 months. However, converting from no-till to conventional tillage increased the speed	Converting from no-till to conventional tillage increased runoff by 38%.	Relevance: 7 Robustness: 8	The article only considers runoff only at a local scale.

	USA. Land had been under a no till regime for 7 years prior to the study. Plots were 2.4x6.1m and there were 4 replicates of each. It's not clear if the experiments were repeated in each of the 4 replicates.	measured from areas of 2x1.5m within each plot.	(runoff started more quickly after the onset of rainfall) and volume (38%) of runoff.			There is no evidence for whether the reported effects are also observed at the catchment scale.
Giertz et al (2005)	Catchment studies investigating impact on runoff and soil properties of land use changes in two ~3km^2 subcatchments in tropical, sub-humid Aguima catchment, central Benin, West Africa. Upper Aguima (UA) subcatchment with natural savannah and forest land cover is subject to annual man-made bush fires. Upper Niaou (UN) subcatchment is used for agriculture (yam, maize, manioc).	Comparison of natural UA subcatchment and agricultural UN subcatchment to analyse effects of land use change. Variety of monitoring approaches used including pedobiological surveys and comparative studies of soil saturated hydraulic conductivity, bulk density and saturated water content; soil water dynamics; and discharge dynamics.	In a dry year, annual runoff from cultivated subcatchment >120mm higher than from natural subcatchment; in wetter year, annual runoff from cultivated subcatchment 74 mm higher than from natural subcatchment. However, significant differences between different crops and tillage systems reported. Cultivated soil water content is higher than natural soil water content due to the higher ET and water withdrawal from savannah and forest.	Reduced activity of macrofauna (worms, termites) in cultivated soils reduces macroporosity, permeability and infiltration capacity, resulting in increased surface runoff and soil loss rates. Cultivation kills macrofauna and destroys biopores.	Relevance: 10 Robustness: 12	This paper is categorised as land management (rather than agriculture or forestry) because the focus is that land use changes cause changes in soil physical properties, which in turn influence surface water and groundwater fluxes and water availability.
Gregory et al (2005)	Farm-scale field studies investigating impact of 3 cropping and tillage patterns (conventional tillage, 5-year crop rotation with tillage in 2/5 years, and no-till) on runoff and soil properties at 3 farms near Northfield,	Catch-basins collected water from narrow strips (~1.7m wide) in the fields at each of the 3 farms. It is unclear how this was standardised between farms and treatments.	Runoff results for the three interventions are given in units of ml cm^{-1} of rain and in each case from four samples. The figures given for conventional, rotation and no-till are, respectively: 684.6+/-631.2, 11.7+/- 9.6 and 19.5+/-11.6.	Differences in runoff from the different cropping and tillage treatments are explained in terms of soil properties. It is noted that the study was conducted during an exceptionally dry year, but it is unclear what impact this may	Relevance: 9 Robustness: 9	It is surprising that the results are not discussed more in the text as they are so different, with a factor of 60 between the conventional and rotation treatments.

	Minnesota, USA.			have on the results.		
Holman et al (2002)	Review report considering the impacts of land drainage on groundwater recharge at field to catchment scales in the UK.	Summary of types and mechanisms of land drainage and literature review of likely impacts on groundwater recharge and baseflow.	In permeable soils, drainage causes an increase in recharge to shallow groundwater and in discharge from it - producing an increase in baseflow – and also a decrease in surface runoff. In low permeability soils, there is no increase in recharge, but low flows are increased by the augmented drainage density.	Land drainage affects natural recharge to groundwater. Land drainage is likely to precede a change in land use. There is potential for land drainage to alter the timing and duration of water fluxes, thereby affecting the water balance.	Relevance: 9 Robustness: 7	The report also includes modelling to provide a quantitative indication of impacts on water fluxes.
Lozano-Garcia et al (2011)	Field studies investigating impact on runoff and soil properties resulting from application of 2 olive mill waste products (olive leaves and “alperujo” from olive oil extraction process) to a rain-fed olive grove in southeast Spain. The study used 3 treatment plots of size 100x100m.	Using 5 mini rainfall simulators (area 625cm^2) within each of the three 10000m^2 treatment plots, rainfall and runoff data were measured and compared with runoff for a control plot with no treatment. This was done 3 years after application of treatments.	After 3 years, runoff from the control was 55.3% but decreases greatly under both treatments to 14.7% (“alperujo”) and 2.8% (olive leaves). There was also a greatly increased time to the onset of runoff in both treatment cases.	Land management to improve soil physical properties can have a notable effect on runoff. Surface application of olive mill waste to rain-fed olive groves significantly reduced runoff compared to no treatment.	Relevance: 9 Robustness: 11	Two very similar papers, both demonstrating the potential to improve soil physical properties through application of organic treatments. It is surprising that the Martinez et al results are not discussed more in the text as the 3-year and 4-year results do not seem entirely consistent.
Martínez et al (2003)	Field studies investigating impact on quantity and quality of runoff resulting from application of 2 organic wastes (biosolids BS and municipal solid waste MSW, both at 90 Mg ha^{-1} dry weight) to a degraded soil in a	Using a rainfall simulator, rainfall and runoff data from the treated plots were measured and compared with runoff for a control plot with no treatment. This was done 3 and 4 years after application of treatments.	After 4 years, BS plots showed minimum total runoff, maximum time to start of runoff and maximum ratio of rainfall to runoff, also minimum sediment yield. After 4 years, control plots showed maximum total runoff, minimum time to start	Surface application of organic waste to semi-arid degraded soil significantly reduced runoff and sediment yield compared to no treatment. BS treatment exhibits greater impact than MSW treatment. Water quality results	Relevance: 8 Robustness: 11	

	semi-arid environment 35km south of Madrid, Spain. A randomised block design utilised 4 blocks, 3m apart, each containing 3 plots 1m apart and of area 0.078m^2.		of runoff and minimum ratio of rainfall to runoff, also maximum sediment yield. After 4 years, MSW plots were intermediate.	suggest that potential contamination of surface water by the organic wastes does not appear to be a limitation to their use.		
Prevost et al (1999)	Paired catchment study exploring impact on runoff and water quality of drainage of peatland soil under well-established (70+ years) black spruce forest near Rivìere-du-Loup, Quebec, Canada.	Rainfall and runoff were measured from two small headwater catchments, one drained (8 ha out of 20 ha total area), and one undrained (18 ha area). Data collected for 16 months pre-drainage and 5-years post-drainage.	There is no effect on tree growth during 5-year post-drainage period. Flows are well correlated pre- and post-drainage. For drained catchment, in dry periods, baseflows increase by ~25%, but in wet periods, no evidence of changes in peak flows.	Drainage appears to cause an increase in baseflows during dry periods, but no changes in high flows during wet periods, though a lack of high flows during pre-drainage period for comparison.	Relevance: 11 Robustness: 12	There is no evidence for whether the observed changes would be sustained and whether they are also seen at the basin scale.
Temesgen et al (2012)	Field studies investigating impact on maize production of 3 tillage systems (conventional, strip, strip with sub-soiling to break plough-pans) at Melkawoba in the semi-arid central rift valley of Ethiopia. Plots were 10x10m.	Detailed monitoring of rainfall, surface runoff and soil moisture over 3 years to quantify the water balance under the three tillage systems.	Runoff from daily rainfall over a threshold of 5-6.5 mm d^{-1} was 20% under conventional tillage, reduced to 13% under strip tillage, and to 9% under strip tillage with sub-soiling.	Tillage practices may have a significant effect on maize production. Plough-pans have a notable impact.	Relevance: 6 Robustness: 11	The focus is about water availability for crop production rather than for direct human use.