Background

The Wular lake constitute a significant linkage in the hydrographic regime of Kashmir valley by acting as a huge absorption basin for flood waters. The lake with its associated wetlands support rich biodiversity as it is an important habitat of migratory water birds and fish resources. The lake has also assumed a significant status in the regional economy of the catchment population as a substantial proportion of the local population is dependent on this lake for their livelihood and employment. A considerable area of the lake has been reclaimed over the period of time which has been utilized for paddy cultivation, willow plantation, residential settlement expansion and other developmental activities in response to the growing economic dependence of the catchment population on the varied products of the lake. The local economy mostly hinges on the subsistence primary economic sector and its allied activities which derive their sustenance from the varied resources of the lake. The daily extraction of the various lake products like fish, water nuts, vegetable products, fodder and fuel wood not only facilitate to meet the daily domestic requirements of the local households but also serve as a source of income to the economically weaker and marginalized sections of the catchment population. However the lack of well defined policy and regulatory mechanisms for integrated management led to cross sectoral conflicts and overall degradation of this important wetland and its varied resource base. Consequently, the area of the lake got reduced from 157.74 sq. km. in 1911 to 86.71 sq. km. in 2007. Recognizing the importance of the wetland for its bio-diversity and socio-economic values, the Wular lake was designated as a Wetland of international importance under Ramsar Convention in 1990. However this international recognition of the water
body did not change much on the ground and lake’s condition continued to degrade day by day.

In order to conserve this important water body, the Government of Jammu & Kashmir has assigned the job of preparing a Comprehensive Management Action Plan (CMAP) to M/S Wetlands International- South Asia in 2006-07. The approach followed for formulation of comprehensive management action plan on Wular Lake emphasizes on development of effective institutional mechanism for conservation and management of Wular Lake within Jhelum Basin. The CMAP is based on evaluation of ecological and socio-economic features of Wular Lake and associated wetlands. The RMAP for Wular lake is a summarized version of the Comprehensive Management Action Plan (CMAP) earlier devised for over Rs.386 Crores and now restricted for an outlay of Rs.120 Crores for 4-years 2011-12 to 2014-15. The RMAP like CMAP seeks a balance between ecosystem conservation and livelihood security to the communities. It also seeks to ensure planning and implementation through an effective institutional mechanism to harmonize planning at various levels with participation of all concerned stakeholders to achieve the objectives of integrated conservation and wise use. However, keeping in view the urgency of activities under land and water management component, specific thrust has been proposed under activities viz survey and demarcation, conservation and water-management. This activity will enhance the water holding capacity of the Lake and its feeder waterways / channels and also slow down the silting by treatment of catchments by different interventions of small engineering works associated with suitable soil and water conservation measures.
As per the CMAP, river basin approach has been adopted for management planning of Wular Lake, which requires treatment of the entire catchment of river Jhelum for control of soil erosion and regulation of flow regimes. However, due to the limited scope of RMAP, the direct catchments has been undertaken on a priority basis. The direct catchment extending to 1,144 sq km comprises 6 watersheds. Madhumati and Erin watersheds located on the northern periphery of Wular, account for 32% and 20% of the catchment area respectively. The southern tip of Wular is enclosed by Ningli and Gundar watersheds. The western flank drainage forms the Wular 1 watershed, whereas Wular 2 is formed of the right bank drainage. The land use of direct catchment is dominated by forests which account for 39% of the overall area. Agriculture and horticulture account for 30% and 10% of the overall area respectively. Pastures account for 8% of the total area. Eleven percent and three percent of the watershed area is under glaciers and high altitude lakes.

The ToR for formulation of CMAP have focused on land & water management, integrated water management, socio-economic development and livelihood improvement and institutional development and capacity building. In order to address the said ToR, the CMAP has laid varied interrelated objectives supposed to be achieved through phased targets by adopting proposed multiple strategies. The main emphasis of CMAP is on restoration of Wular lake for ecosystem conservation and livelihood security of the communities dependent on the lake resources for sustenance. The plan emphasizes on eco-tourism as a potential tool to conserve lake and its rich biodiversity while providing economic incentives to the local communities. The plan is based on adoption of a community based approach to resource management with facilitation from
government agencies and scientific institutions in terms of technical and financial resources.

The objective and aims of RMAP is similar to CMAP and would generally lead to the same benefits. A number of activities are to be carried out to meet these objectives, including

- **Establishment of Wular Development Authority**
- **Water Management**
  - Enhancing water holding capacity
  - Water quality improvement
  - Environmental flow assessment at basin level
- **Catchment Conservation**
  - Erosion control
- **Biodiversity Conservation**
  - Waterbird conservation
  - Wildlife Conservation
- **Establishment of wildlife / bird sanctuaries in the Wular catchment**
- **Ecotourism Development and**
- **Livelihood improvement**

All the activities included in the CMAP, except water management, do not have any direct intervention with Wular lake and will be largely carried outside the lake boundary and its catchment and hence these activities may have hardly any negative impacts to the restoration of Wular lake. However, the water management activity especially enhancing water holding capacity has a direct impact on the lake. In order to increase the
water holding capacity of the Wular lake, CMAP has proposed the removal of Ningli Plantation currently occupying 27.30 sq km. which would help enhancement of water level by at least one meter. Further, selective dredging in critical areas and channels dropping into the lake has also been proposed to create space for biodiversity enhancement. The plan also includes improvising hydrological connectivity with existing marshes that would further help water absorption capacity of the wetland system to control flooding.

The enhancement of 54 per cent water storage capacity of the lake through the removal of 27.30 sq. km. willow plantation and removal of 35.33 MCM of silt constitutes an ambitious target of the proposed CMAP with far reaching hydrological, ecological and socio-economic impacts. Before initiating action on the different management plans envisaged under Revised Management Action Plan (RMAP), the state government planned to have a Rapid Impact Study (EIS) carried out in relation to the removal of willow plantation and dredging based on secondary sources of data. In order to have an assessment of the likely impacts of RMAP, the state forest department of government of Jammu & Kashmir Government have entrusted this job to the Centre for Research & Development (CORD), University of Kashmir with this agreement to have a Rapid EIS based mainly on secondary sources of data.
The Wullar Lake Development Authority has come up with the Comprehensive Management Action Plan (CMAP) for initiating various interventions for the restoration and conservation of the Wullar lake in Phase-I. The proposed action items/schemes have been critically analyzed for the environmental impacts using available data from various sources. The environmental and other impacts of the each of the proposed action items/schemes outlined under the Phase-I of the project are discussed in the following sections.

**Perspective and Visionary Management Action Plan**

As per the Comprehensive Management Action Plan (CMAP) for Wullar, the lake area has shrunk from about 218 Sq. Km in 1911 to about 177 Sq. Km in 2007 with massive changes of land cover types and water extent within the lake body. While as the open water spread and lands under marshes have showed a significant decline, the lands under agriculture, plantation and built up have shown the corresponding increase in the area. These changes are a manifestation of the various land surface processes, socio-economic changes, climatic changes and changing agriculture and other farming practices that have occurred in the catchment since 1911. Though the Comprehensive Management Action Plan is based on the analysis of the published and unpublished information from various secondary sources but the information is not sufficient to develop a robust Management Action Plan for a complex lake system like Wullar.
Additionally, much of the information used for prescribing the action items is outdated and inadequate. However, the proponents of the Comprehensive Management Action Plan have pieced and stitched the available information very meticulously but the integrated analysis of the same is missing in the plan.

Therefore, for developing a robust perspective and visionary lake management action plan for Wullar, it is imperative to understand scientifically the reasons for the massive changes that have occurred within the Lake boundaries during the last one-century. The scientific understanding of the causal factors shall help us to develop a robust strategy at multiple spatial scales for restoring the hydrological and biological status of the lake to the semblance of the recent past. Wullar is a complex interplay of various land surface, climatic, hydrological, vegetation and socio-economic processes that act at different spatial scales in the catchment spread over a large area upstream of the lake. Therefore, a holistic and integrated research, encompassing all the aspects of the lake system within and beyond its boundaries, shall help us to generate fundamental knowledge about the recent changes in the lake body. The knowledge, thus generated, should guide the lake managers to plan and implement interventions on long-term basis for reducing the futuristic impacts of the causal factors. Therefore, the lake management authorities shall, on priority basis, commission a research study through a reputed research/academic institutes to investigate the causal factors responsible for the deterioration of the lake environment during the last 100 years. In absence of such a research study, the measures shall continue to be adhoc with very minimal influences on arresting the deterioration of the Wullar.
Figure 1: Showing the variation of Open Water spread in the Wullar Lake at different points in time from 1911 to 2013
Figure 2: Showing the growth and proliferation of aquatic vegetation within the Wullar Lake from 1911 up-to 2013
Figure 3: Showing the extent of Water (open water+aquatic vegetation) in the Wullar Lake from 1911 up-to 2013
Disposal of Dredged Nutrient-rich Sediments

The dredged sediments are very rich in nutrients and therefore need appropriate disposal and utilization. These sediments could be used to landfilling, landscape improvement or disposed elsewhere depending upon the need, suitability and feasibility in the immediate catchment of the lake. In no case shall these dredged sediments be dumped and left exposed to the vagaries of weather in the open as they could easily find its route back to where they were dredged either through surface flow or base flow. The lake authorities should devise a proper sediment disposal mechanism so that these sediments, once dredged, are proper utilized and fixed in nature so they don’t find its easy way back into the lake through various land and water surface processes.

Table 1: Showing the extent of water spread in the Wullar lake since 1911

<table>
<thead>
<tr>
<th>Year</th>
<th>Extent of the Water Spread (ha) in Wullar</th>
</tr>
</thead>
<tbody>
<tr>
<td>1911</td>
<td>8958</td>
</tr>
<tr>
<td>1954</td>
<td>9741</td>
</tr>
<tr>
<td>1969</td>
<td>7615</td>
</tr>
<tr>
<td>1979</td>
<td>7780</td>
</tr>
<tr>
<td>1992</td>
<td>7949</td>
</tr>
<tr>
<td>2001</td>
<td>8158</td>
</tr>
<tr>
<td>2005</td>
<td>6359</td>
</tr>
<tr>
<td>2013</td>
<td>7318</td>
</tr>
</tbody>
</table>

Promoting alternate sources of Energy

The lake development authorities have plans to promote alternate sources of energy in the immediate catchment of the lake under the Phase-I of the project. The proposed development of woodlots, smokeless hearths, LPG and solar energy shall ameliorate the energy situation in the region and thus, reduce the pressure of meeting the energy demands of the local populace on the adjacent forests. This is going to have a long-term positive affect on minimizing the sediment load from these catchment areas.
However, it would be more prudent to promote the development of micro- and mini-hydropower energy potential in the immediate catchment of the Lake, particularly the Erin and Madhumati watersheds. It is pertinent to mention here that these two watersheds have quite a good hydropower potential for harnessing the same for the development of the alternate sources of energy in the catchment and shall go a long way in reducing the dependence of the local populace on forest resources for meeting the fuel wood requirement for energy.

Figure 4: showing the location and extent of the built-up areas in the vicinity of the Wullar Lake.
Catchment Conservation

**Prioritization of the Immediate Catchment**

The budgetary constraints for the Wullar lake management has prompted the lake managers to prioritize the lake restoration schemes and the same have been detailed under the Revised Comprehensive Management Action Plan for the Wullar lake. The decision of initiating the land and water resources conservation measures in the immediate catchment of the lake comprising of Erin, Madhumati, Nigli, Gunder, Wular1 and Wular2, though not based on any scientific understanding but given the funding constraints, the plan seems plausible keeping in view the quantum of the available grants in the first phase. However, we don’t have any credible and verifiable estimates of the nutrient and sediment loads from these immediate catchments into the lake. Therefore, the identification and prioritization of these immediate watersheds and then the sub- and micro-watersheds within the prioritized ones should be based on the scientific analysis of a whole set of watershed characteristics that control the production and the movement of nutrients and sediments from the catchment to the lake body. The land cover and slope just two of these characteristics and may not give an appropriate zonation of the prioritized watersheds and sub-watersheds. In addition to these two parameters, the prioritization should take into consideration morphometric, hydrological, pedological and climatic variables that control the rate of production and movement of nutrients at watershed scale. Even the land use practices need to be taken into account for arriving at the most appropriate prioritization
scheme. The Department of Remote sensing, Govt. of J&K who have already been engaged for characterizing of the land surface features within and beyond the Wullar lake could be given this task of watershed prioritization in the immediate catchment.

**Best Management Practices for sediment and Nutrient Control**

The measures of treatment should not be confined to the mitigation of the soil erosion only by promoting afforestation and plantations but include measures aimed at the control and treatment of all the nutrients. Therefore, a set of Best Management Practices (BMP) should be promoted in the basin for the long-term control of the nutrient loading to the lake from the immediate catchment. These BMP could include vegetated buffers, crop rotations, construction of artificial wetlands, rejuvenation of springs and wetlands, water quality improvement measures, crop residual management, pastureland management, minimal use of fertilizers and nutrient management for water quality improvement.

**Enhancement of the Water Holding Capacity of the Lake**

There is no doubt that the accumulated sediments from the catchment area have substantially reduced the open water extent of the lake as is evident from the Figure 1. These sediments being enriched in nutrients act as a catalyst for the growth and development of the aquatic vegetation that has now proliferated over the large area of the lake body (Fig 2). The total extent of the waters (Open water + water under the aquatic vegetation) is shown spatially in the Fig. 3 and statics of the same is given in the Table 1. The aquatic vegetation has almost exponentially grown in the lake due to the nutrient enrichment and has expanded and colonized the vast areas of
the lake at the expense of the open waters. The depth of the lake has also reduced to a great extent because of the siltation by the sediments transported from the catchment.

The accumulated sediments in the lake have adversely impacted the water quality and even the recreation and navigation functionality of the lake. The growth and proliferation of the aquatic vegetation has been mainly attributed to the nutrient rich sediments that have accumulated since the last one century. However, there has been no scientific study for the Wullar lake to see if the dredging of the sediments from the lake is environmentally feasible or if it is the most effective solution for improving water quality, recreation and navigation in the long run. We don’t have even the exact idea of how much sediment has accumulated in the lake. The observation data on lake bathymetry, sediment quantity and quality is missing to make such type of calculations for the lake. Further, the lake authorities need to have a clear idea of the depth to which the sediments should be dredged. Dredging too shallow may uncover nutrient-rich sediments and provide a perfect habitat for the aquatic vegetation to grow and proliferate, if the bottom gets enough sunlight.

It is therefore recommended that the lake authorities need to have the sediment cores of the lake analyzed by a qualified expert and also initiate bathymetric surveys to determine the appropriate depth and location of the dredging so that the optimal benefits of the lake dredging are achieved effectively in the long run. However, there is no doubt that dredging the lake to the desired depth and in selected locations (that needs to be determined scientifically as discussed above) shall enhance the water holding capacity of the lake to a great extent. Dredging the lake
wholesome and hotchpotch without these scientific considerations could be prohibitively expensive in terms of the ecological and economic costs. The choice about the type of the dredging equipment, whether mechanical or hydraulic, is left to the lake authorities depending upon the costs and other feasibility considerations. However, depending upon the sediment situation, quantum and magnitude, the use of mechanical equipment may be more feasible.

**Sewage Management in Urban Peripheral Towns**

Phase-I of the comprehensive Management Action Plan for Wullar envisages sewage management and solid waste disposal from the peripheral villages and towns of the Wullar lake that could reduce the nutrient load that directs drains into the lake from these built-up areas. Figure 4 shows the location and extent of the urban areas in the vicinity of the lake. Though, Bandipora is the major urban center in the immediate vicinity of the lake but there are several other towns in the vicinity that may be draining the waste directly or indirectly into the Wullar. Therefore, it needs to be determined how many of these hutsments are directly or indirectly connected with the surface and sub-surface drainage system of the lake so that the proposed sewage treatment is effective and long-lived.

Similarly, the solid waste disposal along the peripheral villages and towns needs to be centralized and the wastes need to be scientifically disposed off by constructing a state-of-art facility for the scientific disposal of the solid waste from all of these built-up enclosures in the vicinity of the Wullar lake. The facility should have the provision of the segregated disposal of the solid waste items type-wise. The recommended facility should be able
to handle the futuristic solid waste load from the immediate vicinity based on the scientific and realistic projections of the waste generation for another 25 years or more.

**Promoting alternate sources of Energy**

The Lake development authorities have plans to promote alternate sources of energy in the immediate catchment of the Lake under the Phase-I of the project. The proposed development of woodlots, smokeless hearths, LPG and solar energy shall ameliorate the energy situation in the region and thus, reduce the pressure of meeting the energy demands of the local populace on the adjacent forests. This is going to have a long-term positive affect on minimizing the sediment load from these catchment areas.

However, it would be more prudent to promote the development of micro- and mini-hydropower energy potential in the immediate catchment of the Lake, particularly the Erin and Madhumati watersheds. It is pertinent to mention here that these two watersheds have quite a good hydropower potential for harnessing the same for the development of the alternate sources of energy in the catchment and shall go a long way in reducing the dependence of the local populace on forest resources for meeting the fuel wood requirement for energy.
Willow Plantation Removal and Dredging in Wular lake

Degradation and loss of wetlands have occurred, and resource managers have recognized the need for wetland restoration. The relatively recent recognition of wetland functions and values has also resulted in regulatory reforms that often dictate restoration of wetlands. However, wetland restoration as a branch of ecology and as a practice is still in its infancy and this is also the case of wetlands and lakes of Kashmir.

Ecological restoration is the practice of restoring and managing ecosystems. The practice requires vision of what the restored ecosystem should look like, understanding of the ecological processes needed to restore and maintain the ecosystem, and specific skills and techniques necessary to carry out the work (Anderson 1996). Other specific components include identifying stresses that are degrading the ecosystem, formulating realistic goals, establishing reference sites and measures of success, conducting experiments to test ideas and methods, monitoring results, and further testing or readjusting methods to achieve the goals.

Case studies of projects to reverse eutrophication reveal a mix of successes and failures. These studies illuminate the processes that stabilize eutrophication, as well as strategies for breaking down the resilience of the eutrophic condition and restoring clear water. In some cases, eutrophication has been halted or reversed by reducing phosphorus inputs (Edmondson 1991). Success is most common in lakes that are deep, with
cold, oxygen-rich deep waters. In other cases, successfully-managed lakes have rapid flushing rates. Whether deep or rapidly flushed, these lakes have great capacity to dilute phosphorus and maintain oxygenated conditions. Also, some lakes which recovered rapidly from eutrophication were eutrophic for only a few years. Such lakes may not accumulate a large mass of phosphorus in the sediments.

Determining levels of acceptable and unacceptable change to a range of variables influenced by riparian willows would need to be addressed. These should include litter quality and quantity, lake community metabolism, channel aggradation, large woody debris (LWD) dynamics, riparian DOM sources, thermal regulation, macrophytic vegetation, invertebrate and fish communities each of which can be strongly influenced by riparian vegetation. Changes to any of these variables could be beneficial or detrimental depending on the context. An additional multidisciplinary challenge is thus to determine when a change in a parameter is beneficial and when detrimental. Quantifying the impacts of willows and willow removal at multiple levels of ecosystem organization and evaluating under which circumstances such changes are beneficial or harmful is a complex combination but one which is necessary to provide management direction (Wilson 2001).

However, willow infestations are now extensive in and around the Wullar lake and elsewhere, with substantial adverse impacts on wetland hydrology and biodiversity. Invading willows, forming dense stands of trees or shrubs with extensive, thick root mats, can cause destruction of indigenous vegetation communities, elimination of faunal habitats, alteration of lake hydrology, decreased water quality and increased water use from the
The CMAP broadly focuses on biodiversity conservation and maintaining ecological processes and functions through land and water management. The Wullar Lake Management Plan identifies willow plantation as a major environmental issue. The plan calls for removal of willows from the lake, including bank stabilisation and a dredging program. Water savings might arise directly from reduced evapotranspiration, and indirectly from improved hydraulic efficiency of the lake.

**Potential effects of willow removal on water quality**

As per the CMAP the water quality of Wular lake has deteriorated over a period of time due to discharge of high levels of untreated sewage into the wetland and falls within category C as per CPCB’s designated best use criteria. The CMAP proposes to improve the water quality of Wular lake to B category as per CPCB designated best use criteria through management of sewage and sewerage from adjoining settlements by constructing sewage treatment plans, constructed wetlands and sanitary units. Although CMAP has focused on treatment of domestic sewage coming from the settlements it does not mention about the treatment of pollution caused by effluents released from the adjacent agricultural lands, and sediments brought by the rivers and nallas into the Wular lake. The silt load not only fills the lake but it also adds lot of nutrients into the lake system their by reducing the water quality.

The CMAP also does not mention the impact of removal of plantation and large scale dredging on existing water quality. It has been reported that management of streams and other freshwater bodies have had unintentional

aquatic systems.
negative consequences for native ecosystems. It is estimated that 21.84 lakh trees (total 27.30 sq km) need to uprooted using manual and mechanical means from Wular lake. Specific areas to be covered under the activity are: Watlab to Wular Outlet (2.75 sq km), Ningli to Maqdoomyari (9.15 sq km), Maqdoomyari to Banyari (Laharwalpora side) (3.95 sq km), Laharwalpora to Kanusa (3.23 sq km) Kanusa to Zurimanz (0.17 sq km).

The areas to be dredged have been classified into three zones:

a) Areas presently under willow plantation which may be dredged to an average depth of 1.5 meters,
b) Critically silted areas along the shorelines of Wular to be dredged to a depth of 0.75 meters, and
c) Waterways and watercourses to facilitate better water circulation

Removal of plantation and dredging in the Wular lake in the long term is not only expected to increase the water holding capacity of the lake but will also facilitate in restoration of the water quality and enhancement of biodiversity and ecosystem functions. However, the large scale removal of willows and dredging could also have negative impacts on the lake if it is not managed with proper planning. The removal of vegetation and dredging operations are long established human induced disturbances in lakes and rivers and are responsible for making change the environmental features of the water bodies (Pranovi et al., 1998).

The decision to remove, leave or otherwise manage willows in lakes, streams, rivers and wetlands is a much debated topic between natural resource managers, academics and the broader community. The debate is complicated due to the large knowledge gaps and inconclusive and conflicting findings on the effects of willows on aquatic biota and a lack of
literature on the effects of removing willows from aquatic ecosystems. Priority setting requires quantitative knowledge of impacts, costs and benefits from willow plantation and willow removal at both lake and catchment scales (Wilson 2001). In addition, catchment managers require access to knowledge that will enable willow removal to be undertaken in a manner that minimizes detrimental short term impacts and accelerates recovery of the system. The potential effects of removing willows on aquatic systems has called for further information to be gathered on the effects of willows and willow removal on Wular lake ecosystem.

**Introduction to Willows**

Belonging to the family Salicaceae, the genus Salix comprises about 450 species worldwide distributed mostly in the Northern Hemisphere (Argus, 1997). Although predominantly occurring in temperate and arctic zones, willows are also present in subtropical and tropical zones and include trees, shrubs and groundcovers. The geographical distribution of willows includes all continents except Antarctica. In J&K about 15 species of willow have been reported, out of which two species namely Salix alba and S. Fragalis, are mainly found in Wular lake.

Species of the genus Salix differ in their ecological distribution and can be divided into two major groups: alluvial or riparian (growing along rivers, stream banks and point bars) and wetland (growing on saturated soils). In both situations willows form relatively stable successional stages (Skvortsov, 1999; Kowalchik, 2001). The important adaptations and limitations of willows as pioneer species include their ability to colonize nutrient-limited oligotrophic sites such as bogs, river sand, wetlands and lakes; formation of symbiotic associations with mycorrhizal fungi which
provide an additional supply of nutrients for plant growth (Salix species benefit from vesicular-arbuscular endomycorrhizae that utilize phosphorus, as well as ectomycorrhiza that use organic nitrogen); adapted to hypoxic conditions, and preference for both mineral and organic soil. They have commonly been used for bank stabilisation, erosion control, boat navigation and as ornaments (Perkins 1903; Rodd 1982). Salix also represents a promising resource in mitigating impacts of environmental degradation. The versatility of the genus Salix for remediation in environmental projects is emphasized by the following fact that of 15 types of soil chemical degradation listed by Logan (1992), Salix offers remediation of 10 (erosion, mine spoil, industrial waste, dredge spoil, ore smelters, sewage sludge, petroleum spills, oil shale waste disposal, nuclear waste and landfills). Developing applications are designed to alleviate the major environmental pollutants: mineral nutrients, heavy metals and organic compounds addressing major environmental issues such as soil degradation, water eutrophication, habitat destruction and accumulation of greenhouse gases in the atmosphere.

The essential physiological characteristics that affect Salix suitability for environmental restoration projects include:

- Superior growth and productivity even at juvenile stages; the highest capacity to convert solar radiation into chemical energy among woody plants under certain climatic conditions (Christersson et al., 1993; Wilkinson, 1999).

- Extensive fibrous root system in the many shrub-type species, with the majority of fine-roots found in the upper 40–45 cm of the soil profile; continuous growth of fine roots from May through October (Gray and
Sotir, 1996; Rytter and Hansson, 1996).

- High rates of evapotranspiration during the growing season (Lindroth, 1994; Lindroth et al., 1995; Ledin, 1998; Ebbs et al., 2003).

- Efficient uptake of nutrients (Ericsson, 1981; Elowson, 1999); high filtering capacity for nitrogen; ability to facilitate denitrification in the root zone (Aronsson and Perttu, 2001).

- Tolerance of flooded or saturated soils and oxygen shortage in the root zone (Jackson and Attwood, 1996; Krasny et al., 1988; Aronsson and Perttu, 2001; Kuzovkina et al., 2004a); some species are tolerant to increased concentration of carbon dioxide and methane (Maurice et al., 1999).

- Ease of vegetative propagation due to preformed root primordia on the stems, and possibility of vegetative reproduction from horizontally lain willow rods (Carlson, 1950; Gray and Sotir, 1996).

- Vigorous re-establishment from coppiced stumps (Ceulemans et al., 1996; Philippot, 1996).

- Ability to accumulate high levels of toxic metals, especially Cd (Klang-Westin and Eriksson, 2003).

However, willows are highly invasive due to the trees remarkable ability to spread and the habitat created by water regulation. Willows grow best when they are near water (Schulze and Walker 1997) and this has facilitated their invasion with water acting as an ideal transport mechanism for branches and seeds. The ability to rapidly colonise available habitats
allows willows to invade watercourses, as well as spreading along stream, wetland and river banks. The tree roots which spread into the bed of a watercourse, can potentially slow water movement, reduce aeration, encourage sedimentation and alter the shape of the stream bed, often making it broad and shallow (Bunn et al. 1993).

Willows were grown as plantations in valley in the available marshy and barren areas of Kashmir, including Wular lake mainly to provide firewood. Through a series of experiments, willow was found to be most suitable for marshy areas and Robinia for drier sites. Willows currently represent a significant and potentially important component of Wular lake ecosystem. Systematic plantation within the marshes associated with Wular lake was initiated in 1916. By 1924, the Ningli plantations were established and transferred under the administrative control of the then Sindh Forest Division and subsequently expanded continuously under the Plantation Division of Forest Department, Government of Jammu and Kashmir.

The State Department of Rakhs and Farms, constituted to manage and administer the marshes reclaimed for agricultural purposes further undertook the willow plantation in a major way after the 1950s. The Department promoted plantations in shallower zones of the marshes and water bodies primarily to provide fuelwood and in the later stages to support match and cricket bats manufacturing industries. In the later stages, social forestry division undertook willow plantations within the Wular Lake during 1982 – 2002 under the state government funded scheme on wasteland plantations, covering an area of 0.12 square kilometres. Village Panchayats, encouraged by the immense revenue
potential of the willows also undertook plantations in 0.55 square kilometer area.

Following the Jammu and Kashmir State High Court Orders dated 10 October 2006 instructing the State Government to demarcate the territorial limits of the Wular and Manasbal Lakes, an assessment of the area under willow plantation in and around the lake was made by the Revenue Department in three tehsils of Sonawari, Bandipora and Sopore. The survey indicated an area of 34.88 sq km presently under willow plantation in 30 peripheral villages. Of this, the state government departments of Forests, Rakhs and Farms and Social Forestry account for 86% (30.29 sq km) of the willow area. Preferences for willows are related to their easy vegetative propagation of rooted and unrooted cuttings, tolerance to flooding and periodically saturated soils, fast growth and formation of extensive fine fibrous root systems capable of binding sediments.

Given the possible deleterious effects of willows on aquatic processes, the large scale willow removal projects are currently underway in Wular lake. A widely established view has emerged that fundamental freshwater ecological processes may be affected by willow spread, causing a broad range of detrimental impacts to freshwater ecosystems (Bobbi 1999; Smith and Star 1999).

Willows are deciduous, with soft, fragile leaves that fall in late autumn and provide a large flux of rapidly decomposing organic matter to aquatic systems (Legssyer et al. 2003). Branches and bark from willows also have a fast decomposition rate. Also both the bark and leaves of willows leach cyanidins, delphinidins, leucoanthocyanidins and phenolglycosides into aquatic environments which have shown to deter herbivores (Rowell-
Rahier, 1984). The thick, overhanging canopy of willows crowds native plants and casts heavy shade which decreases the amount of solar radiation reaching the surface water (Lester et al., 1996). This can affect water temperatures and primary production and can alter growing conditions for native understory vegetation.

**Table 2. Willow characteristics and their associated possible environmental impacts.** (Adapted from the North East and Murray Willow Management Working Group 1998)

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Possible Environmental Impacts of Willows</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deciduous</td>
<td>Dense shade in spring and summer, followed by light shade and heavy leaf fall in autumn and winter, suppresses indigenous understorey and river fauna. Most leaves fall in autumn when natural stream flows are high and water temperatures low. The massive leaf drop in autumn can lead to high nutrient pulses within the system and to reduced water quality.</td>
</tr>
<tr>
<td>Dense shallow mat-forming roots</td>
<td>Roots and foliage trap silt build up on the ground surface and divert flows into banks. Eventually watercourses may change course to flow around willows, creating ‘braided’ streams with mid-stream islands. Streams with willows tend to become wider and shallower. This leads to increased flooding, until the channels have expanded. Roots generally suppress growth of indigenous plants, leaving bare ground beneath.</td>
</tr>
<tr>
<td>Dense canopy</td>
<td>Dense shade created by tree canopies can decrease light availability and water temperatures (especially during spring/summer). These modifications may cause a decline in in-stream primary production: limited regeneration of native flora and a decrease in dissolved oxygen concentrations.</td>
</tr>
<tr>
<td>Lack of predators or terrestrial willow-eating animals</td>
<td>Willows contribute little to the terrestrial food chain. Fewer insects results in fewer insectivorous birds. Few insects drop into the watercourse to provide food for fish etc. Lack of predators allows willows to grow faster than indigenous plants, and suppress indigenous understorey growth.</td>
</tr>
<tr>
<td>Monoculture forming, Ability to dominate entire sections of the watercourses</td>
<td>Dominance of stream banks leads to marked reductions in natural diversity of flora and fauna and habitat/conservation values in the water and on the banks. Watercourses dominated by willows may not be as accessible as typically indigenous watercourses.</td>
</tr>
<tr>
<td>Ability to spread</td>
<td>Willows can spread prolifically vegetatively and by seeding between different willows. As such, they are highly invasive and have the potential to dominate watercourses. Such potential poses severe environmental risks to other areas, including intact ‘natural’ areas.</td>
</tr>
<tr>
<td>Tendency to grow into the centre of streams and cause erosion</td>
<td>Willows can grow in continually wet sediment and hence encroach towards the centre of watercourses. Such encroachment can create flow diversions which increases erosion potential, and can lead to complete stream blockages as the trees trap silt and debris. This increases flooding, and can cause streams to change course.</td>
</tr>
<tr>
<td>Tendency to accumulate debris</td>
<td>Willow debris deposited downstream can continue to grow causing further problems. Additionally, long overhanging willow branches or numerous trunks encourages the collection of debris, which increases stream blockages and redirects flows into banks where erosion may occur.</td>
</tr>
</tbody>
</table>
Few branches shed, and few hollows or snags formed

Willows are poor habitat for hollow-dependent mammals and birds, and snag dependent fish. Fallen branches that either rot quickly, reducing food resources for in stream invertebrates, or take root, spreading willows further.

Brief flowering season

Willow flowers only provide nectar for introduced honey bees, for a brief period. There are no records of use of flowers by nectar-feeding birds.

Water use

Willows can dry out streams and swamps by using more water than the herbaceous vegetation they replace, or have higher transpiration rates than indigenous species.

Fig. 5: Ecological impacts of willow plantation

Willow removal will have very different ecological outcomes depending on a variety of factors including:

- whether it is a regulated/non regulated river section or a wetland or stream,
- the ecological character of the water body (i.e. invertebrate and fish assemblages, primary productivity etc.) and
- the physical conditions of the water body (i.e. presence of other vegetation, bank stability, water temperature, flows, depth and size etc.).
The high infestation rate of willows coupled with a steady shift within aquatic management authorities from a ‘resource-engineering management paradigm’ toward a ‘watershed ecosystem (integrated catchment) paradigm’ (Healey 1998) has led to much focused debate over best willow management within academic, management and broader communities (Wilson 2001). Attempts to remove willows from the riverbanks have been met with strong community opposition, but there is similar opposition to leaving them unchecked (Kennedy et al. 2003). Despite this controversy, few studies actually detail the environmental effects of willows and fewer studies describe the effects of removing them.
Effects on Transparency and Turbidity

The short and long term effects of removing willows on transparency and turbidity are very difficult to predict and will vary between areas depending on water flow, size, depth, sediment, climate, geology, and topography. Where there is no risk of erosion occurring, removal of whole willows from the centre of watercourses may have the most immediate positive impacts, preventing further disturbance in geomorphology and restoring the natural watercourse. Removal of whole willows along banks may prevent further changes in lake or stream morphology, however, erosion and associated channel and ecological changes would need to be considered. Large scale willow removal can impact on the ecology of the lake with a high possibility of silt release and soil destabilisation occurring following removal. This has the potential to increase turbidity and blanket aquatic habitat with silt. Suspended sediments can alter taste, odor, temperature and abrasiveness of water (Oschwald, 1972) and reduce levels of dissolved oxygen, particularly in deeper, thermally stratified lakes (Appleby and Scarratt, 1989; Cramer, 1974). Increases in sediment inputs have also been noted to decrease pH at the substrate-water interface (Lemly, 1982). A decrease in water clarity is another obvious change resulting from an increase of suspended solids. Increased turbidity, associated with suspended solids, reduces the penetration of sunlight. This in turn reduces photosynthetic activity and limits primary production (Munavar et al., 1991).

The removal of willows from drier areas of the Wular lake will not have any significant impact on the transparency or turbidity of the lake water. However, removal of willows from within the lake inundated by waters
will significantly decrease the transparency and increase turbidity by releasing the silt and soil, although, the impact will be only for short term. It is recommended that the willows should be removed during lean period so that impact on the water is minimized. However, dredging can significantly increase the turbidity and thereby reduce the transparency. During the present investigation the transparency values decreased to 8% only when the dredging was in progress but after dredging the transparency values restored to about 67%. Similarly the suspended solids also increased during dredging (Table 3&4) and returned just about to the values found at un-dredged areas. The study reveals that the removal of willows and dredging will have short term impact on the transparency and turbidity of Wular lake waters.

There are numerous direct and indirect impacts of silt, suspended sediments and associated turbidity. These include changes to water quality, reduced light penetration, diminished recreational values and aesthetics as well as direct and indirect impacts to fish, invertebrates, and aquatic plants.
View of bottom sediments seen after dredging in Wular lake.

Table 3: Transparency and turbidity at certain locations in Wular lake during present investigation.

<table>
<thead>
<tr>
<th>Sites</th>
<th>Depth (m)</th>
<th>Transparency (cm)</th>
<th>Total suspended Solids(mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boniyari Main</td>
<td>1.2</td>
<td>32.0 (26.6%)</td>
<td>117</td>
</tr>
<tr>
<td>Boniyari II</td>
<td>0.5</td>
<td>21.33 (42%)</td>
<td>285</td>
</tr>
<tr>
<td>Makhdoomyari</td>
<td>0.6</td>
<td>35.5 (59.6%)</td>
<td>222</td>
</tr>
<tr>
<td>Ningel</td>
<td>5.5</td>
<td>41.14 (7.48%)</td>
<td>348</td>
</tr>
<tr>
<td>Watlab</td>
<td>1.8</td>
<td>42.67 (23.70%)</td>
<td>352</td>
</tr>
<tr>
<td>Saderkot Bala</td>
<td>0.8</td>
<td>53.34 (66.6%)</td>
<td>217</td>
</tr>
</tbody>
</table>

Table 4: Transparency and turbidity during dredging and after dredging in Wular Lake during present investigation

<table>
<thead>
<tr>
<th>Sites</th>
<th>Depth (m)</th>
<th>Transparency (cm)</th>
<th>TSS (mg/l)</th>
<th>TDS (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>During Dredging</td>
<td>0.8</td>
<td>10.5cm (8%)</td>
<td>1788</td>
<td>325</td>
</tr>
<tr>
<td>After Dredging</td>
<td>0.8</td>
<td>53.34 (67%)</td>
<td>336</td>
<td>300</td>
</tr>
</tbody>
</table>

Effects on nutrient dynamics and other allied aspects

The removal of willow leaf litter input into Wular lake through willow removal may reduce high nutrient pulses and overall nutrient levels in the
long term. This may decrease the potential for eutrophication and toxic algal blooms to occur and has the potential to lead to increased water quality. However, the removal of such a large input of nutrients could also affect the food source of invertebrate and fish populations. However, the removal of willows from the buffer zone, will also lead to an increase in the amount of nutrients, chemicals and sediment entering the Wular lake, and possibly to a reduction in water quality (Schoonover et al., 2005).

Effects on Light

Light is a vital factor controlling aquatic ecosystems (Rutherford et al. 1997). Vegetation plays an important role in regulating light intensity (Hill 1996; Bunn et al. 1999) and spectral qualities (Van Kraayenoord et al. 1995). Mature willows produce dense canopies, which significantly reduce the availability of incident illumination to underlying water body (Lester et al. 1994a; Gehrig and Ganf 2003). Lester et al. (1994a) found a reduction in incident photosynthetically active radiation (PAR) of 80% in summer and of at least 50% in winter in New Zealand willow-lined streams.

Increased light resulting from de-willow operations could have long term impacts on various biological aspects within the aquatic systems. In the Ovens River, NSW, photosynthetic irradiance was found to be more than 5 times greater in recently de-willow sites than in the reference reach (Gawne et al. 2005). Possible changes in a system could include increases in germination, establishment, growth and survival of native vegetation, increases in water temperature, increases in primary production and changes in planktonic composition (Van Kraayenoord et al. 1995). The ability of riparian vegetation to significantly reduce primary production in streams through shading was first documented by Allen
(1951) and this has been confirmed elsewhere (Keithan and Lowe 1985; Hill and Harvey 1990; Quinn et al. 1997). Thus the removal of shade following a de-willowing operation in Wular lake could directly increase primary production and indirectly increase secondary productivity and invertebrate densities and affect shifts in the number of taxa from particular functional feeding groups (Plafkin et al. 1989). This in turn could indirectly lead to further changes in the trophic structure such as in fish and bird communities with the magnitude of effect likely to be greatest in shallow regions of the Wular lake where wetland vegetation has the greatest impact (Lamberti and Steinman 1997, Rutherfurd et al. 1997). However, most of the area to be de-willowed in the Wular lake are not inundated by lake waters and although some parts of the lake are immersed by waters during rainy season and floods, they remain dry for most part of the year. Hence, impact of willow removal on lake ecosystem will be minimum and restricted to the regions where willows are submersed with the lake waters.
Effect on Temperature

Water temperature plays a large role in aquatic ecosystems structure and function. It can affect development and growth of aquatic insects (Butler 1984), growth, reproduction and disease resistance in adult fish and hatching and development of fish larvae (Pusey and Arthington, 2003). Elevated water temperatures also increase the metabolic rate of lake dwellers, thereby decreasing dissolved oxygen concentrations and impacting adversely on lake assemblages (Rutherford et al. 1997).

Willow canopies play a significant role in controlling the transfer of thermal energy to aquatic systems and in determining temperatures in lakes and wetlands (Van Kraayenoord et al. 1995). A reduction in vegetation cover can result in greater mean summer water temperatures (Lynch et al. 1984; Quinn et al. 1992; Pearson and Penridge 1992), lower winter water temperatures (Lynch et al. 1984; Amour et al. 1994) and an increase in the degree and rate of change of daily fluctuations of water temperature (Lynch et al. 1984; Quinn et al. 1992). These effects would be most evident in lotic systems (lakes and wetlands) and in small and shallow streams (Quinn et al. 1997; Rutherford et al. 2004). Lake systems are particularly sensitive to modifications in shade because, for a given surface heat flux, the rate of temperature variation is inversely proportional to depth (Rutherford et al. 2004).

However, Gawne et al. (2005) found no immediate difference in water temperatures between de-willowed sites and reference sites in non summer months, despite a significant loss of shade in the de-willowed reaches. In the long-term, increases to light penetration following willow removal may increase water temperature over summer months. Temperature changes of
this magnitude can have a significant effect on aquatic ecosystems. Increased temperatures can lead to decreased dissolved oxygen levels, affecting different life stages of invertebrate (Nebeker 1996) and fish species (Llewellyn 1973; Pearson and Penridge 1992). It should also be noted that some invertebrates and fish have low upper thermal tolerances so the immediate impact of large scale willow removal or the complete removal of willows in one area on thermal regimens should be recognized. Especially if removal is done over the summer months when it has been shown that thermal regimes of large water bodies may be influenced by willows. The impact of willow removal on temperature of Wular lake will be minimum and restricted to the regions where willows are submersed with the lake waters. However, the mean temperatures are expected to be increased during summer and lower during winter due to large scale removal of willows plantations in the area.

**Effects on Nutrients**

Total nitrogen (TN) and total phosphorus (TP) levels present in an aquatic system can indicate how nutrient polluted (eutrophied) or vulnerable the system is to nuisance plant growth. The large influx of organic matter into aquatic systems from willows can have significant influences upon nutrient fluxes in aquatic environments (Royer et al. 1999). Upon entering the water, willow leaves rapidly leach simple organic compounds such as reducing sugars, amino acids and phenolic compounds (Iversen 1974; Gessner and Schwoerbel 1989). As much as 25% of the nitrogen, 50% of the phosphorus and 85% of the potassium in the leaf is rapidly released to the water column (Taylor and Barlocher 1996). Willow leaves (*S. viminalis*) were reported to have relatively higher N concentrations (e.g. up
to 1.8% litter dry mass [DM]) when compared with grey alder (Alnus sp.) leaves that have N-fixing symbionts (2-3% DM) (Haapala et al. 2001), and had higher initial N and P concentrations than Populus and Platanus species (Casas and Gessner 1999). Lester et al. (1994b) found that willow leaves submerged in a stream for 56 days possessed approximately three times as much N and carbohydrate, twice as much protein, and similar amounts of chlorophyll a as periphyton.

This suggests that while willow leaf litter is decomposing, it can contribute to elevated nutrient levels in lakes and wetlands. Leaf litter decomposition rates are regulated by temperature (Legssyer et al. 2003), nutrient availability, oxygen availability, current velocity, hyphomycete diversity, the number of invertebrates present and litter chemistry (Baldy et al. 1995). Willow leaves have a rapid decomposition rate mainly due to physical abrasion and leaching and biological aspects including mineralization and modification. These processes lead to the formation of CO₂ and other inorganic compounds, dissolved and fine-particulate organic matter and decomposer biomass (Webster and Benfield 1986; Suberkropp 1998; Gessner et al. 1999). This can increase nutrient leaching rates within a system with studies showing that as much as three times the amount of soluble nutrients (630 μg/g) can be leached from physically abraded leaves compared to intact leaves (Cowen and Lee 1973) and this volume can be further increased during flooding events (Glazebrook and Robertson 1999). So removal of willows from Wular lake will decrease the amount of nutrients entering the lake through leaf litter annually from the willow plantations.

On the other hand, increased nutrient input into water courses can also
result from the removal of willow vegetation zones (Schoonover et al. 2005). These zones act as buffers to diffuse and decrease the velocity of surface water runoff and promote infiltration, sediment deposition, and nutrient retention as well as reduce nutrients in groundwater (Dosskey 2001). High nutrient and light conditions favour the development of filamentous algae which invertebrate consumers do not readily consume (Bunn et al. 1999). The increase of nutrients, namely N and P and filamentous algae can lead to eutrophication, which has been shown to impact negatively on invertebrate taxa (Merritt and Cummins 1996) and fish diversity (Sleehausen et al. 1997). Eutrophication can also lead to the development of toxic algal blooms which reduce water quality and decrease dissolved oxygen levels (Codd 1995) leading to anoxic conditions that can lead to stress and potential death in aquatic biota (Oliver and Ganf 2000).

Table 5: Nitrogen and phosphorus concentrations in willow leaf litter from the Murray and Murrumbidgee rivers. Data are means ± standard deviation. (Source: Esslemont et al. in prep)

<table>
<thead>
<tr>
<th>Tree</th>
<th>Leaf Condition</th>
<th>N (M.Kg⁻¹)</th>
<th>P (M.Kg⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Willow</td>
<td>Fresh</td>
<td>0.95 ±0.16</td>
<td>0.061 ±0.018</td>
</tr>
<tr>
<td>Willow</td>
<td>Weathered</td>
<td>0.82 ±0.12</td>
<td>0.052 ±0.011</td>
</tr>
</tbody>
</table>
Table 6: Nutrients dissolved in Wular lake water at different sites during present investigation

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Ammonical-nitrogen µg/l</th>
<th>Nitrate-nitrogen µg/l</th>
<th>Total Phosphorus µg/l</th>
<th>Ortho-phosphorus µg/l</th>
<th>Sulphate mg/l</th>
<th>Sodium mg/l</th>
<th>Potassium mg/l</th>
</tr>
</thead>
<tbody>
<tr>
<td>Banyari inlet</td>
<td>110</td>
<td>233</td>
<td>185</td>
<td>85</td>
<td>12.0</td>
<td>8</td>
<td>4.0</td>
</tr>
<tr>
<td>Banyari II</td>
<td>135</td>
<td>246</td>
<td>330</td>
<td>132</td>
<td>25.0</td>
<td>10</td>
<td>4.0</td>
</tr>
<tr>
<td>Makhdoomyari</td>
<td>264</td>
<td>807</td>
<td>295</td>
<td>106</td>
<td>30.0</td>
<td>8</td>
<td>4.0</td>
</tr>
<tr>
<td>Ningel</td>
<td>187</td>
<td>235</td>
<td>200</td>
<td>95</td>
<td>33.0</td>
<td>9</td>
<td>4.0</td>
</tr>
<tr>
<td>Watlab</td>
<td>190</td>
<td>296</td>
<td>350</td>
<td>118</td>
<td>35.0</td>
<td>7</td>
<td>3.0</td>
</tr>
<tr>
<td>Saderkot Bala</td>
<td>186</td>
<td>289</td>
<td>360</td>
<td>130</td>
<td>28.0</td>
<td>13</td>
<td>5.0</td>
</tr>
</tbody>
</table>

Table 7: Nutrients dissolved in Wular lake water at different sites during dredging and after dredging

<table>
<thead>
<tr>
<th>Site</th>
<th>Ammonia (µgL-1)</th>
<th>Nitrate (µgL-1)</th>
<th>Total Phosphorus (µgL-1)</th>
<th>Sodium (mgL-1)</th>
<th>Potassium (mgL-1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>During dredging</td>
<td>147</td>
<td>172</td>
<td>245</td>
<td>11</td>
<td>6</td>
</tr>
<tr>
<td>After Dredging</td>
<td>48</td>
<td>167</td>
<td>51</td>
<td>10</td>
<td>3</td>
</tr>
</tbody>
</table>

During the present investigation the physical and chemical composition of Wular lake water at different locations are similar to the levels observed in other lakes of Kashmir (Table 6 & 8). Despite large supplies of nutrients from the catchment area and the sediments brought by the rivers directly entering into the lake, the levels of nutrients (NH₃, NO₃, P, SO₄, Ca, Mg, Na, K) in the lake waters are low. The nutrient levels did not show any significant change also during dredging or after dredging, when compared
to other sites (Table 7 & 9). Infact most of the nutrients levels recorded after dredging were slightly low with respect to other lake sites. Similar results have also been observed in Dal Lake, where water quality has improved after de-weeding and dredging operations (LAWDA, 2011-13; Project on Monitoring of Dal lake Ecosystem; by CORD KU). However, long term assessment is needed to drive at any conclusion especially monitoring the impacts on lake biota.

Mechanical dredging in Wullar lake near Nigli

Organic Inputs

Organic inputs into lakes from overlying vegetation provide a strong influence on aquatic community structure and ecosystem processes (Casas and Gessner 1999). They provide critical energy sources for aquatic food webs (Allan 1996) and so underpin the energetics of the aquatic ecosystem (Webster et al. 1997; Benfield 1997). For example, Fisher & Likens (1973) reported that nearly 99% of the energy in Bear Brook, New Hampshire,
was derived from riparian vegetation. Generally the greatest proportion of leaf litter entering freshwater systems comes through the direct vertical input of leaves (i.e. leaf drop through leaf abscission or senescence) and to some extent through lateral inputs (leaf drop through wind, run-off etc.) (Sabater et al. 2001). The quantity and composition of organic inputs is influenced by the age, species and health of the riparian vegetation (Bunn et al. 1993). The dense leaf mass of wetland willows supply large amounts of allochthonous organic matter into aquatic systems (Gregory et al. 1991). The deciduous nature of willows means that peak litter inputs occur in late autumn (Murphy and Giller 2000; Gawne et al. 2002), and smaller pulses of litter inputs may occur in summer during times of low flow as a result of leaf abscission induced by water stress (Sabater et al. 2001). Calculations undertaken by Latta (1974) ascertained that 25.5 kg (dry weight) of leaves would be shed in autumn by a willow tree with a diameter of 0.5 m. Therefore, in a given waterway section with willows spaced at 10 m intervals on both banks, over 5000 kg km$^{-1}$ would be deposited into the river and onto the banks (Latta 1974).

Willows are planted for their ability to stabilise degraded banks and retain sediments. Hence, a major concern following willow removal is the mobilization of fine sediment and organic matter, and of the nutrients contained within, when willow roots retaining these materials rot away (Wilson 2006). This process is predicted to last for at least five years (Holland-Clift & Davies 2007; Rutherfurd 2007). The negative impacts of fine sediment deposition and nutrient enrichment on freshwater ecosystems are well-known (Wood and Armitage, 1997; Allan, 2004). However, there are hardly any studies that have quantified sediment and nutrient loads released after willow removal (Wilson, 2006).
The removal of willows from Wular lake, will also be removing the large annual input of organic materials into the system. In the long term, the removal of this organic input may alter processing rates by resident microbes and invertebrates, affect lake energetics and decrease the levels of nutrients which may decrease the potential for eutrophication and toxic algal blooms to occur and has the potential to lead to increased water quality. However, the removal of willows from the buffer zone (Edge; outside demarcated lake boundary) will also lead to an increase in the amount of nutrients, chemicals, pollutants and sediment entering the aquatic system from the direct catchment and will have negative impacts on the water quality. It is therefore highly recommended that the willow removal should be only restricted within the lake boundary (demarcated by bund), while leaving the buffer zone intact. Infact buffer zone can be used
for willow plantation wherever, it is not present considering the importance of willows to filter the nutrients, trapping of sediments, erosion control and stabilization of bunds. However, continuous monitoring is needed to check their invasion within the lake boundary.

It is also suggested to built settling basins on the pattern of Dal lake on all the major inlets of the Wular lake. The settlings basins will not only check the pollution but will also prevent the lake from siltation. The silt deposited in the basins can be extracted by giving contract to the people associated with sand mining in the Wular lake.

Table 8: Physico-chemical parameters of water during present investigation at different sites in Wular lake

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Water Temp.</th>
<th>pH</th>
<th>Cond. (uS)</th>
<th>TDS (mg/l)</th>
<th>DO (mg/l)</th>
<th>TA (mg/l)</th>
<th>Cl (mg/l)</th>
<th>TH (mg/l)</th>
<th>Ca (mg/l)</th>
<th>Mg (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Banyari Inlet</td>
<td>18</td>
<td>7.3</td>
<td>229</td>
<td>153</td>
<td>4.4</td>
<td>112</td>
<td>18</td>
<td>90</td>
<td>24.36</td>
<td>17.46</td>
</tr>
<tr>
<td>Banyari II</td>
<td>17</td>
<td>8.1</td>
<td>356</td>
<td>239</td>
<td>6.0</td>
<td>164</td>
<td>28</td>
<td>140</td>
<td>34.44</td>
<td>32.34</td>
</tr>
<tr>
<td>Makhdoomyari</td>
<td>16</td>
<td>7.6</td>
<td>332</td>
<td>226</td>
<td>5.2</td>
<td>124</td>
<td>12</td>
<td>130</td>
<td>36.96</td>
<td>22.56</td>
</tr>
<tr>
<td>Ningel</td>
<td>10</td>
<td>7.5</td>
<td>313</td>
<td>213</td>
<td>4.4</td>
<td>138</td>
<td>18</td>
<td>120</td>
<td>29.4</td>
<td>27.9</td>
</tr>
<tr>
<td>Watlab</td>
<td>11</td>
<td>7.7</td>
<td>316</td>
<td>212</td>
<td>6.4</td>
<td>116</td>
<td>13</td>
<td>124</td>
<td>28.56</td>
<td>31.56</td>
</tr>
<tr>
<td>Saderkot Bala</td>
<td>15</td>
<td>8.2</td>
<td>456</td>
<td>310</td>
<td>4.0</td>
<td>202</td>
<td>45</td>
<td>152</td>
<td>37.8</td>
<td>34.5</td>
</tr>
</tbody>
</table>

Table 9: Physico-chemical parameters of water during dredging and after dredging in Wular lake

<table>
<thead>
<tr>
<th>Sites</th>
<th>pH</th>
<th>Cond. (uS)</th>
<th>TDS (mg/l)</th>
<th>TA (mg/l)</th>
<th>Cl (mg/l)</th>
<th>TH (mg/l)</th>
<th>Ca (mg/l)</th>
<th>Mg (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>During Dredging</td>
<td>7.71</td>
<td>500</td>
<td>325</td>
<td>226</td>
<td>20</td>
<td>250</td>
<td>78</td>
<td>34</td>
</tr>
<tr>
<td>After Dredging</td>
<td>7.64</td>
<td>448</td>
<td>300</td>
<td>236</td>
<td>18</td>
<td>246</td>
<td>72</td>
<td>41</td>
</tr>
</tbody>
</table>
Hydrological Alterations

Hydrology is a major factor determining the composition of wetland plant assemblages (Busch et al. 1998). Long-term changes in wetland inundation can dramatically change community structure and composition. Prolonged flooding favors submerged and floating vegetation (van der Valk et al. 1994), while shorter inundation periods favor woody species (Timoney & Argus 2006).

Hydrological regimes of Wular Lake are primarily linked with Jhelum and its tributaries. Jhelum flows through Wular Lake, entering at Baniyari and exiting at Sopore. The lake is also drained by Erin and Mudumati nallah from the Bandipura district. Although, there is a marked absence of detailed information on hydrological regimes of Wular lake, the assessment in CMAP of Wular lake which is mostly based on the information made available through the weekly discharge records of State Irrigation and Flood Control Department estimates that

- River Jhelum is the largest contributor of water inflows (88%) into Wular, the rest being from the immediate catchments and precipitation. Similarly, the outflows through River Jhelum is the highest (96.9%), the rest accounted for by human abstractions (1.7%) and evapotranspiration (1.4%).
- There is a high temporal variability in inflows and outflows. Eighty percent of the inflows and 86% of the outflows take place in summer.
- The net outflows from the Wular (measured at Sopore) are higher than the inflows.
However, the assessment is lacking the flow of water from groundwater sources (springs located in the catchment and within the lake) which is also depicted by the more outflow. It is suggested to take the assessment of flow from all the Nallahs and ground water sources. Besides transpiration rates does not seem to be in coherence with the amount of vegetation located within the lake. The plantation and agriculture has increased about 26.64 sq km and 43.87 sq km respectively from 1911 to 2007. During the same period the area under associated marshes has decreased to about 41.0 Sq km which has been mainly converted to agriculture. Most of the area under marches in Wular lake has been converted into plantation which is the main cause of reduction in water holding capacity together with siltation.

Management of streams and other freshwater bodies has had unintentional negative consequences for native ecosystems. Effective management requires a better understanding of how changes in hydrology affect expansion by woody species and exacerbate loss of native wetlands.

Springs located in the vicinity of Wular lake
The CMAP also mentions a decline by one fifth of the water holding capacity of the lake over the last three decades mainly due to willow plantation leading to high drainability and reduced capacity of the wetlands to regulate flow regimes. Raising of willow plantation has severely altered the hydrological processes of the wetland. These plantations act as barriers to silt laden waters of the river Jhelum forcing it to discharge the sediment load into the lake and thereby inducing loss of water holding capacity. A spatial analysis of the sedimentation pattern within the wetland clearly indicates rapid siltation along the fringes of the plantation areas. The CMAP targets to enhance present water storage capacity by 54%, through removal of willows from 27.30 sq km and 35.33 MCM of silt through selective dredging, proving an opportunity to rejuvenate the hydrological functions of the wetland, and thereby improve biodiversity and resource base for supporting livelihoods of local communities.

Water uptake by riparian or wetland plantation is highly variable and depends on the tree species, tree dimension, local moisture conditions and climate (Lambs and Muller 2002). Studies conducted on the San Pedro River in south-eastern Arizona, US, found that willows (Salix gooddingii) only used groundwater for transpiration and did not utilise water from rainfall events from the upper soil layers (Snyder and Williams 2000). However, many arguments have been based on removing riparian willows due to their potential ‘high water usage’. A study conducted between August 2005 and March 2006 “Quantifying water savings from willow removal in creeks” in central NSW (New South Wales) Australia demonstrated that willows located in waterways used 3-4 MLYear^{-1}ha^{-1} more water than river red gums located on stream banks (Benyon and Doody 2006). The study also showed that water quantities used by willows
and river red gums did not differ when comparing willows and river red gums on stream banks (Benyon and Doody 2006). The potential for willows to utilise more water is only likely to manifest when willows invade water-courses.

The results of the 16 simulations of evapotranspiration from willows are listed in Table 10. Predicted mean annual evapotranspiration ranged from 1250 mm year\(^{-1}\) if willows have low maximum stomatal conductance and high stomatal sensitivity to VPD (vapour pressure deficit), to 1900 mm year\(^{-1}\) if willows have high maximum stomatal conductance and low stomatal sensitivity to VPD. This compares to expected evaporation from an unshaded water surface of 1700 to 1800 mm year\(^{-1}\) and 240 mm year\(^{-1}\) from non-saturated bare soil.

*Table 10: Simulated mean annual evapotranspiration, mm year\(^{-1}\). Includes rainfall interception loss, transpiration and surface water and soil evaporation. (c.f. Benyon and Doody, 2006)*

<table>
<thead>
<tr>
<th>Minimum stomatal resistance (s m(^{-1}))</th>
<th>36</th>
<th>24</th>
<th>18</th>
<th>12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Threshold sat. vap. deficit (kg kg(^{-1}))</td>
<td>1250</td>
<td>1440</td>
<td>1570</td>
<td>1740</td>
</tr>
<tr>
<td>0.010</td>
<td>1300</td>
<td>1490</td>
<td>1620</td>
<td>1780</td>
</tr>
<tr>
<td>0.026</td>
<td>1410</td>
<td>1600</td>
<td>1710</td>
<td>1860</td>
</tr>
<tr>
<td>0.052</td>
<td>1480</td>
<td>1660</td>
<td>1770</td>
<td>1900</td>
</tr>
</tbody>
</table>

The simulations produced estimates of mean annual evaporation from unshaded water of 1720 to 1820 mm year\(^{-1}\). Thus if minimum stomatal resistance of willows is moderate to high, willow annual water use is predicted to be lower than evaporation from an open water surface.
Evaporation from unsaturated bare soil was predicted to be 240 mm year$^{-1}$. Therefore a large difference in evapotranspiration between willows having unlimited access to water from the creek, and evaporation from bare soil on the creek banks was predicted. Removing willow crowns from above bare soil was predicted to save between 10.1 and 16.6 ML ha$^{-1}$ year$^{-1}$. Taking this into account, Figure 6 illustrates the simulated mean annual water savings under each scenario, showing the relationship between simulated willow annual water use and net annual water saving for ratios ranging from willows shading only water to willows shading an equal area of water and dry soil.

Figure 6: Simulated net annual water saving from willow removal for different ratios of shading of open water/wet soil to dry soil (c.f. Benyon and Doody, 2006)
However, the results of the field study were unexpected and contrary to the assumptions of the simulated modelling. The willows in the creek bed had transpiration rates about six times higher, on average, than that of the bank willows, reaching a peak of 15.2 mm day\(^{-1}\) in summer compared to a peak of 2.3 mm day\(^{-1}\) in the bank willows. The average water use of the ‘wet’ willows through the peak period was approximately 12 mm day\(^{-1}\) which was 25% higher than the maximum predicted by the model for this climate and was about 30% higher than published estimates of point potential ET for this region (Wang et al. 2001).

Overall, daily and cumulative water use (total evapotranspiration) by willows and red gums on the creek bank was about the same (Figures 7 and 8), while willows in the creek bed were estimated to have higher evapotranspiration than the amount of water that could be evaporated from open water. The modelling carried out in stage one of the study, predicted a median net water saving from willow removal of approximately 2-4 ML ha\(^{-1}\) for a scenario whereby willow water use is moderate and willows shade twice as much water/saturated soil as they do dry soil. The results of the field study suggests a 3-4 ML ha\(^{-1}\) water saving is possible by removing willows, although there is a low degree of statistical confidence associated with this estimate (Table 11). However, the willows must be situated in the stream bed with permanent access to water if that saving is to be achieved.
Figure 7: Daily water use during each measurement period based on crown projected area. (c.f. Benyon and Doody, 2006)

Figure 8: Cumulative total water use, 3 August 2005 to 18 May 2006, based on crown projected area. (c.f. Benyon and Doody, 2006)
Table 11. Measured or estimated water balance components and calculated total evapotranspiration from willows and open water from August 2005 to July 2006. *(c.f. Benyon and Doody, 2006)*

<table>
<thead>
<tr>
<th>Water Use Site</th>
<th>Rainfall (mm)</th>
<th>Interception (mm)</th>
<th>Evaporation (mm)</th>
<th>Transpiration (mm)</th>
<th>Total ET (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Willows - bank</td>
<td>314</td>
<td>26</td>
<td>257</td>
<td>280</td>
<td>563</td>
</tr>
<tr>
<td>Willows - creek</td>
<td>314</td>
<td>26</td>
<td>330</td>
<td>1633</td>
<td>1989</td>
</tr>
<tr>
<td>Open water</td>
<td>314</td>
<td>-</td>
<td>1642</td>
<td>-</td>
<td>1642</td>
</tr>
</tbody>
</table>

There is still considerable uncertainty about the potential water saving achievable by willow removal due to the wide range for transpiration among different willow species in different climates and also due to uncertainty about evaporation rates from the shaded water surface under the willow canopy compared to unshaded water without willows.

Once willows are removed from the lake there is likely chance of their recurrence from the left out stumps, roots and fallen branches. Willows have the ability of vegetative propagation due to preformed root primordia on the stems, and possibility of vegetative reproduction from horizontally lain willow rods (Carlson, 1950; Gray and Sotir, 1996) and vigorous re- establishment from coppiced stumps (Ceulemans *et al.*, 1996; Philippot, 1996). This has also been the case of Dal lake where the willow plantation was removed under the order of Hon’ble High Court in 2007, and as on today the whole area is back under dense willow vegetation. It is highly recommended to remove the whole trees including the roots. The sites must be monitored and treated for any regrowth or reinvasion by willows or other weeds for several years after initial control is conducted.
Willow removal operation in progress in Wular lake

Stumps with roots left on the site in Wular lake after removing willows have high potential for regrowth
Willow removal along with roots in at some sites in Wular lake

Willows have high reoccurrence potential from vegetative propagation
Experiments have showed that hydrological manipulations can be a powerful tool in controlling the establishment and early growth of willows (Quintana-Ascencio et al., 2013). Timely desiccation and flooding can control willow by killing seedlings and reducing growth of cuttings. The success of water level manipulations depends on timely application of drawdown or flooding. Once seedlings persist into the wet season, most mortality occurs during flooding events. Maintaining relatively high water levels (+50 cm above soil level) during the wet periods can reduce establishment of willow seedlings (Quintana-Ascencio et al., 2013). Once established as a large sapling or tree, willow can persist under both hydrologic extremes (prolonged drought and high water conditions: >1 m water depth). Neither soil compaction nor flooding significantly reduced growth of cuttings of several species of willow under greenhouse conditions (Kuzovkina et al. 2004). Most willow (Salix) species have physiological adaptations that improve persistence in areas subjected to water level variation. Carolina willows established from cuttings tolerate hypoxic conditions and grow in compacted soils, allowing them to tolerate prolonged flooding (Kuzovkina et al. 2004). Most plant species cannot persist under extended inundation because water limits diffusion of CO₂ and O₂ (Armstrong et al. 1994). However, several species of willow produce aerenchymatous, adventitious roots that mitigate anoxia which allows them to survive under these harsh conditions (Kuzovkina et al. 2004).
Willows produce adventitious roots when the water level is high in Wular Lake.

Willows located on dry lands are occasionally flooded with water only in spring time or during high rainfall.
Willows stabilize the bunds and also check erosion into the lake
Table 12: Potential long term effects of willow removal on aquatic processes

<table>
<thead>
<tr>
<th>Part of willow removed</th>
<th>Process</th>
<th>Potential effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Root mat</td>
<td>Channel morphology</td>
<td>? Change</td>
</tr>
<tr>
<td>Root mat</td>
<td>Bank erosion</td>
<td>? Increase</td>
</tr>
<tr>
<td>Root mat</td>
<td>Sediment size</td>
<td>? Increase</td>
</tr>
<tr>
<td>Canopy</td>
<td>Light levels</td>
<td>Increase</td>
</tr>
<tr>
<td>Canopy</td>
<td>Temperature</td>
<td>Increase</td>
</tr>
<tr>
<td>Canopy</td>
<td>Nutrient input</td>
<td>Decrease</td>
</tr>
<tr>
<td>Canopy</td>
<td>Organic input</td>
<td>Decrease</td>
</tr>
<tr>
<td>Canopy</td>
<td>Understorey vegetation</td>
<td>Increase</td>
</tr>
</tbody>
</table>
Impact of Dredging on Water Quality and Hydrology

Dredging temporarily degrades water quality by suspending sediments and increasing water column turbidity (Morgan and Chuepagdee 2003; Rheault 2008). These solids are comprised of silt, clay and peat/organic particles and toxic substances. Hydraulic dredges use water jets to liquefy the substrate, dispersing fine silt and clay into the water column, elevating turbidity, and creating a sediment plume downstream of operations, transporting and redepositing sediment into adjacent areas (Vining, 1978). Larger sand particles are redeposited near the dredge while considerable amounts of fine silt and clay particles remain in suspension and may be carried away by currents (Godcharles 1971; Tuck et al. 2000). Substrate type determines the amount of suspended solids in a plume and how long it persists, while the distance and direction of the plume is primarily controlled by water currents (Tarnowski 2006). The largest plumes, highest turbidity, greatest light attenuation levels, and slowest plume decay rates are generally produced in shallow water environments containing high silt and clay content (Ruffin 1995; Tarnowski 2006).

The CMAP envisages to increase the water holding capacity of the lake by selective dredging of silted lake areas which has been critically affected by siltation and willow plantations within the lake periphery (Table 13). The mechanical dredging is proposed in a) areas presently under willow plantation which may be dredged to an average depth of 1.5 meters, b) critically silted areas along the shorelines of Wular to be dredged to a depth of 0.75 meters, and c) Waterways and watercourses to facilitate better water circulation.
Although, the dredging map proposed in CMAP identifies certain critical areas, the proper identification of the areas is lacking. Vast area of the Wular lake remains dry during most part of the year and is mainly used for grazing by domestic animals. Further, the CMAP proposes removal of about 27.63 sq km of plantations, but on the other hand area to be dredged under willow plantation is 7.47 sq km only. It is recommended to include these areas (Willow removal areas and drylands) in the dredging plan which will not only increase the water holding capacity of the lake further but will also help in reducing the impacts of domestic animals. After removal of willows the area will be used for grazing by domestic animals which can pollute the lake by pugging and release of organic matter.

Further it was also observed during the present survey that the dredging carried by JPCs in the Wular lake is not scientific particularly when dredging is carried in the lake waters. The JPCs should only be used for dredging in dry lands, while hydraulic dredging should be employed in the lake water on priority basis as has also been proposed in CMAP.

Some of the impacts due to dredging are discussed below:

### Table 13: Proposed areas to be dredged in Wular lake

<table>
<thead>
<tr>
<th>Location of areas to be dredged</th>
<th>Area</th>
<th>Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) Willow Plantation Area</td>
<td>7.47 sq km</td>
<td>11.20 Mcum</td>
</tr>
<tr>
<td>b) Critically silted lake areas</td>
<td>20.25 sq km</td>
<td>15.19 Mcum</td>
</tr>
<tr>
<td>c) Channels</td>
<td></td>
<td>0.15 Mcum</td>
</tr>
</tbody>
</table>
• Dredging on dry land mass that has filled up by sedimentation to increase the water expanses will not pose serious threat to water quality of the lake. However, the amount of sediments removed should be properly managed so as to check its reentry into the lake.

• Dredging in the water expanses of Wullar lake to increase the water depth may deteriorate water quality on short term basis in the lake. The fine sediments will remain in suspension in plume and may be transported by water currents into adjacent area. Disruption of surface sediments by dredging could create short term and localized oxygen deficits in the water column (Bartoli et al., 2001), and increase concentration of nutrients/ contaminants, COD and BOD in water column for short term. Physical changes in sediment compaction from dredging can alter the magnitude and rate of biogeochemical cycling between the sediment and overlying water (Badino et al., 2004). Disruptions of the substrate increase the rate of resuspension and enhance the upward flux of nutrients in water column. The dredging on long term basis will improve the water quality by increasing the water depth, which could prevent the resuspension of bottom sediment and decrease the upward flux of nutrients. Furthermore, dredging would remove the sediments which act as sources of nutrients hence would retard internal loading to lake and improve the water quality of the lake.

• Dredging reduces biodiversity on short term basis by crushing, burial/ removal or capturing organisms directly in dredges blades or resuspended in the sediment plume (Pranovi et al. 1998). The physical action of the dredge removes macrofauna and smaller organisms such as polychaetes and amphipods (Kyte and Chew 1975) by resuspension, alteration of habitat complexity, especially in low structure soft
Recolonization after dredging is an ongoing process depends on recruitment rates, restoration of sediment structure and sediment stability, wave action, natural disturbance. The reestablishment of benthic communities and recovery of infaunal abundance, taxonomic richness and biomass following dredging occurs within days, to weeks (Ferns et al. 2000), or months (Ismail 1985: Spencer 1997) with recovery often complete within one year (Simon and Connor 1977).

Over all dredging will increase the diversity in dredged areas due to mobilization of resources and the creation of spatial patchiness, factors which may promote recolonization by a new suite of species (Grave and Whitaker 1999). Small scale disturbances caused by dredging can create a spatial and temporal mosaic of successional states which can enhance community diversity (Tarnowski 2006). Dredge disturbance can prevent any one species from becoming dominant, resulting in a more diverse biological community (Collie et al. 2005).
Domestic animals grazing on dry lands near Zaina Lank which was once surrounded by lake waters

Dry lands elevated due to siltation from flooding has decreased water holding capacity of the Wular lake
Pugging caused by domestic animals when land is saturated with water can severely impact the lake water quality
Construction of roads into the lake for dredging with JPCs is not scientific.

Leaching of material from sediments into the Wular lake waters after dredging
Introduction

The decision envisaged in the Comprehensive Management Action Plan for Wular Lake, Kashmir regarding the mass removal of willow plantation and massive dredging for maintaining the desired water depth was indeed a big decision but not without element of risk. The proposed plan impregnated with imprints of hydro ecological risks is intricate and complicated to be defended from scientific and operational point of view because of the large knowledge gaps, insufficient data sets and inconclusive and conflicting findings on the effects of willows on aquatic biota, as very few such case studies are available on the effects of removing willows from aquatic ecosystems world over. Assuming that the benefits of this unique strategy will outweigh the risks, it however needs to have a continuous monitoring even after this major intervention is over. Determining levels of acceptable and unacceptable change to a range of variables in the lake ecosystem by removal of willow plantation, hydrological intervention and shift in regime change would require the adoption of rigorous experimental designs focused on target key parameters most likely to be influenced by intended operation (willow removal) and would be beneficial to address knowledge gaps (Wilson 2001). Under such a scenario the most difficult job is thus to determine accurately and precisely when a change in a parameter is beneficial and when detrimental. Quantifying the impacts at multiple levels of ecosystem organization and evaluating under which circumstances such changes are beneficial or harmful is indeed a complex combination but one which is
definitely going to pave the way in the management of lake ecosystems. (Wilson 2001).

Macrophytes and even the tree plantation along the banks of the lake ecosystems is an essential component of lake ecosystems and any loss or disturbance in this pattern can have a large impact on aquatic fauna and their associated trophic structures (Thompson and Townsend 2003; Danger and Robson 2004). Regarding the Wular lake it has unusual pattern wherein the macrophytes as well the willow plantation are not only on the banks of the lake but well in the interior of the lake. The interaction between the physical effects of dewilling, the possible associated ecological effects and the complexity of food webs and aquatic community structure is diverse and complex than normally presumed. Under these circumstances the removal of willow canopy and macrophytic vegetation through dredging of vast area within the Wular Lake is likely to have both direct and indirect short-term affects (STA) and long-term affects (LTA) on aquatic biodiversity.

The essential physical and chemical factors that may be altered as a direct result of willow canopy removal and dredging may influence lake processes and other biological communities in the Wular lake include:

1. Increase in photosynthetically available radiation (PAR) resulting from a decrease in shade (PAR = light) (LTA).
2. Increase in water temperature resulting from a decrease in shade and an increase in PAR (LTA).
3. Removal of above ground foliage and habitat (STA and LTA).
4. Decrease in the amount of autochthonous organic input entering the water body as a result of removing the annual leaf litter fall (LTA).
5. Removal of habitat destruction for bacteria, algae, invertebrates, fish especially nesting and breeding grounds of birds due to habitat destruction that can reduce the phosphate concentration to the lake (STA and LTA).

6. Increase in the turbidity and nutrient concentration due to resuspension (STA).

7. Reduction in the recreation and aesthetic values (STA)

8. Imbalance in Carbon offset (LTA)

The interplay of these factors and the effects they can have in a basic aquatic food chain in Wular lake while undergoing massive dredging and de willowing can be best understood by the graphical representations (c.f. Zukowski, S. and Gawne, B. (2006) in Figs. 9&10.

**Effects of Removal of Willow Canopy and Trunk on biodiversity**

![Figure 9: Possible long-term direct (−) and indirect (- -) effects on a basic freshwater trophic chain through an increase in light and temperature, foliage / habitat removal and a decrease in organic input following the removal of willow canopy and trunk.](image-url)
Effects of Removal of Willow Root Mass on Biodiversity

Decrease in Organic Input

Aquatic Habitat Removal

- Birds
- Fish
- Bugs
- Algae
- Bacteria
- Carbon

Figure 10: Possible long term direct (→) and indirect (←) effects on a basic freshwater trophic chain through habitat removal and a decrease in organic input following removal of willow root mats.
Potential Impact on Phytoplankton and Zooplankton

Lake ecosystems have been proved exceptionally promising ecosystems for studying biological community shift patterns as these are fundamentally similar in many ways. The possibilities for comparisons make it easier, however, as our systems and Wular being no more exception are data deficient systems wherein long term data is not available to understand the processes and factors that lead to the regime shifts of phytoplankton and the resilient ones to withstand. Therefore the primary objective remains to review the observations and findings of plankton regime shift patterns in other parts of the world to have an insight on likely implications of major hydro biological intervention on the plankton community in Wular lake. Change in the lake phosphorus cycle due to regeneration from sediments temporarily is going to trigger the increased growth rate of phytoplankton and in extreme cases may become causal factor for bloom formations (Cyanobacteria). This can at times be followed by creation of anoxic episodes. An extensive and methodical study regarding the phytoplankton biodiversity status of Wular lake is highly needed to draw some inferences on the potential impact of said project.

The Wular lake being largest freshwater lake in India acts as huge reservoir of nutrients as all the rivers and streams of river Jhelum basin ultimately enter into the lake. Therefore, it has the bearing on the productivity of the lake ecosystem. Taking account of this mega watershed and lack of sewerage facility wherein in the sewage directly enters into lake there seems every likelihood of continuously enriching the lake with phosphorus apart from other nutrients till the causal factors continue to
operate. The fate of the amount of P in the lake water shall be governed by
the watershed or release from lake sediments, and loss due to hydraulic
outflow or sedimentation. Therefore phosphorus in sediment have the
potential to be released to the overlying water, however some of the
phosphorus may be removed from lake through proper dredging which is
currently being practiced in Wular lake. Since there is a well established
correlation between phosphorus concentrations in lake water and
phytoplanckton biomass (Schindler et al. 1978, Canfield and Bachmann
1981), therefore the phosphorus in lake and algal biomass are assumed to
be interchangeable.

The Wular lake being a typical shallow and nonstratified supports large
pacts of rooted aquatic plants. Consequently unique set of processes
govern the transition between clear and turbid water (Scheffer 1997,
Jeppesen et al. 1998). Turbidity imparted temporarily or permanently
depending upon causal factors will lead to the dominance of phytoplankton
as primary producers whilst rooted aquatic plants will be sparse, because
of shading by phytoplankton, uprooting by bottom-feeding fishes and some
waterfowl eat macrophytes. In such a situation, phosphorus release from
sediments may be rapid, because the sediments are exposed to wave action
and are easily resuspended. On the other hand in the clear-water state,
macrophytes, periphyton, and their epiphytes are the dominant primary
producers and phytoplankton concentrations are low and recycling of
phosphorus to phytoplankton is slow, because the rooted plants stabilize
sediments and monopolize nutrients during the growing season. Apart
from this phytoplankton may be grazed heavily by zooplankton because
the macrophytes provide the zooplankton with a refuge from fish
predation.
Phytoplankton composition is affected not only by trophic state of a water body but also by other factors (Reynolds, 1998) such as mixing regime (Ryan et al., 2006), temperature (Paerl and Huisman, 2008; Brookes and Carey, 2001), mainly physico-chemical ones such as pH, light, temperature, water depth and nutrients (Lund, 1965; Nygaard, 1977; Buzzi, 2002; Jeppesen et al., 2005), grazing parasitism (Canter, 1973; Hickman, 1979), euphotic depth to mixing depth ratio, dissolved oxygen concentration (Trimbee and Prepas, 1988; Dokulil and Teubner, 2000) and ratios of macronutrients (Smith, 1983; White et al., 1985; Hamilton et al., 2006). Besides, their importance as the primary producers in food webs and ensuring ecological balance, species of phytoplankton can be useful indicators of water quality (Kitner and Poulickova, 2003; Rey et al., 2004).

There are high quality research reports wherein trophic state of lake has been related to catchment land use, but direct links between phytoplankton taxa and land use have been rarely studied. Since Wular lake also shares huge catchement area and correlations drawn in other parts may give some useful signal regarding the Phytoplankton and catchment relationship. There are well established correlations between various land use patterns and trophic State and also with various groups of phytoplankton (Ref). Studies revealed negative correlation of Trophic state with forest and positively with pasture and urban. Among the phytoplankton groups Cyanophyta were correlated negatively with forest and positively with pasture and trophic state, Chlorophyta were correlated positively with forest and urban land use and negatively with pasture and trophic state and Bacillariophyta were positively correlated with dissolved reactive Silica to Dissolved Inorganic Nitrogen (Si:DIN) and Si to dissolved reactive phosphorus (Si:DRP) ratios. Lakes with higher nutrient
loads had higher trophic state and Cyanophyta dominance. Chlorophyta were negatively correlated with Cyanophyta and Bacillriophyta thereby suggesting competition in these groups. Under the present circumstances the lake is dominated by Bacillariophyceae (Appendix 1) and due to increased nutrient loading may therefore shift towards the dominance of Cyanophyceae.

Some of these factors may be symptomatic rather than causal of the dominance of certain taxonomic groups. For example Cyanobacterial blooms are often associated with reduced water clarity but blooms also influence turbidity and deplete oxygen during the bloom collapse phase (Paerl and Huisman, 2008). Longterm reductions in external nutrient loading has been observed with decreased abundance of Cyanophyta, some increase and decrease in Chlorophyta and increased abundance of Bacillriophyta alongwith Pyrrophyta, Cryptophyta and Chrysophyta. On the other hand, it is found that presence/absence of Cyanophyta and Bacillariophyta genera were closely related with trophic state of lake apart from mixing regime which is a better predictor of phytoplankton composition (Ryan et al. 2006).

Increasing anthropogenic pressure on water resources globally has deteriorated water quality wherein poor water quality is often associated with increased trophic state and occurrence of Cyanophyta blooms (Paerl et al. 2001). The algal blooms due to Cyanophyceae are of particular concern due to their potential toxicity (Codd et al., 2005) unsightly appearance, musty odours and flavours in water (Wood et al., 2011). The abundance of Cyanophyta is reported to be due to specific features like nitrogen fixation (Anabena species), buoyancy regulation and luxury
storage of phosphorus (Pettersson et al., 1993; Zohary and Robarts, 1998). The positive relationship of Cyanophyceae to anoxic to oxic water volume ratio may be related to internal loading of Phosphorus (Sondergaard et al., 2003) and reduced ratios of TN:TP (Smith, 1983). Cyanophyta can also influence through internal loading through decay of blooms which act as a carbon source to enhance bacterial respiration thereby leading to anoxia and increased internal nutrient loading (Paerl and Huisman, 2008). Therefore these types of complex and complicated positive feedbacks amongst Cyanophyta, internal loading, TN:TP ratios are often not resolved by collection and statistical treatment of huge data sets nevertheless it is well established that Cyanophyta depict more prolific growth during quiescent conditions associated with low wind (Ryan et al., 2006). Cyanobacteria also show dominance where ratio of mixing depth to euphotic depth tend to be higher. Proliferation of Cyanophyta increases the turbidity of water thus reducing euphotic depth and increasing the likelihood that mixing depth will exceed euphotic depth. Chlorophyta are often but not always a subdominant group may be due to slower growth rate than other phyla in relation to TP concentration and tolerance of low TP concentration than other phyla. Chlorophyta being a large and heterogenous group (Round, 1963) can become dominant in lakes with high TP concentrations and may show increasing or decreasing trend vis a vis alternate episodes of eutrophy and oligotrophy (Jeppensen et al., 2005). Chlorophyta has also been found to thrive well in highest TN:TP ratio, lowest Si:DIN and Si:DRP ratios and very low reactive silica concentrations (McColl, 1972). Bacillariophyta tend to dominate where Si:DIN and Si:DRP molar ratio is high and also of low trophic state condition (Bellinger and Siegee, 2010). Taking the above mentioned
situation into consideration, the data sets are missing in case of Wular and therefore seems difficult to predict the changes in the plankton community of the lake after the dredging and de willowing.

Shade reduction leads to increased water temperatures (Rutherford et al., 1997), with maximum summer temperatures potentially exceeding upper thermal tolerances of sensitive invertebrate and fish species (Quinn et al., 1994; Richardson et al., 1985). An increase in water temperature is also associated with reduced levels of dissolved oxygen concentrations. Increased light levels, in particular coupled with elevated nutrient concentrations, can also increase primary production (Quinn et al., 1997) and change the periphyton community structure from palatable unicellular algae to prolific filamentous green algae and macrophytes (Bunn et al., 1999). Increased levels of suspended sediment during the operation of dredging coupled with sediment load from inlets have a tendency of interfering with normal physiological and metabolic activity thereby reducing the productivity of algae (Alabaster and Lloyd, 1980). Research works have revealed that an increase in turbidity of 25 NTU (Nephelometric Turbidity Units) in shallow, clear-water systems may potentially reduce productivity by 13-50% or more and be associated with an increase in suspended sediment concentration of approximately 25-100 mg/l (Lloyd, 1985). A 5 NTU increase in turbidity in clear-water systems have been found to reduce the primary productivity by 3-13% or more and be associated with an increase in suspended sediment concentration of approximately 5-25 mg/l. However the effect of the turbidity generated during the dredging operation will be short lived as it is not a continuous process and therefore will have very less impact as is being predicted and envisaged. Turbidity has been reported to influence composition, size,
duration and time of occurrence of phytoplankton pulses and vertical
distribution of microcrustacea in Lake Erie (Chandler, 1942).

A total of 82 species of phytoplankton are reported in which 53 belong to
Bacillariophyceae, 21 to Chlorophyceae, 5 to Cyanophyceae, 2
Euglenophyceae and 1 to Chrysophyceae while the recent reports depict
that (Appendix I). Dominant species found include *Synedra ulna*,
*Navicula* sp., *Gomphonema olivaceum*, *Diatom elongatum*, *Amphora* sp.,
*Cocconeis placentula*, *Fragillaria vaucheriae*, *Cymbella* sp., *Closteridium*
sp., *Scenedesmus* sp., *Euglena* sp., *Dinobryon* sp., *Oscillatoria* sp., and
*Chrococcus* sp. Surprisingly, a recent study restricted to only Watlab Ghat
has revealed only a total of 64 species of phytoplankton dominated by
Bacillariophyceae. (Appendix I). These conflicting figures with respect to
the plankton taxa in the Wular lake will make it difficult to draw
comparisons in future after this intervention as they are struggling for the
authenticity.

The early reports have recorded Fifty species of zooplankton in the Wular
lake of which 37 belonged to rotifera, 9 to cladocera and 4 to copepod
(Appendix I). The predominant species of zooplankters in the Wular lake
were: *Keratella cochlearis*, *Polyarthra vulgaris*, *Ascomorpha* sp,
*Bronchionus quadridentata*, *Filinia longiseta*, *Monostyla bulla*,
*Cephalodella* sp, and *Anuraeopsis fissa* (Rotifera); *Alona costata*,
*Chydorus sphaericus*, *Bosmina longirostris* (Cladocera); *Cyclops seutifer*,
*Paracyclops affinis* and *nauplii larvae* (Copepoda). The authors attribute
the dominance of rotifers in the Wular lake to the increased nutrient
enrichment.

However, recent account revealed a total of 16 species of copepods
belonging to three families (Cyclopoida with 12 species, Calanoida and Harpacticoida with two species each) in which Cyclopoids were found to predominated over calanoids. The most abundant taxa in order of dominance were *Cyclops bicolor*, *Bryocamptus nivalis*, *Eucyclops agilis* and *Cyclops latipes* and other species observed were *Acanthocyclops bicuspidatus*, *C. bicolor*, *Cyclops biseto-sus*, *Cyclops bicuspidatus*, *Cyclops panamensis*, *Cyclops scutifer*, *Cyclops vicinus*, *C. latipes*, *E. agilis*, *Bryocamptus minutus*, *B. nivalis*, *Diaptomus* sp. and *Diaptomus virginiensis*. Additionally 42 species of crustaceans were recorded belonging to three different groups namely cladocera (23), copepod (16) and ostracoda (3). This recent account has shown the dominance of cladocera over copepods (Appendix I).

The outcomes and response of impacts on Zooplankton are reflected in community structure and interactions within the food web. Theories of food-web dynamics focus on the number of trophic levels predicting relatively discontinuous, alternating (high/low/high) changes in biomasses along the food chain and an increasing number of trophic levels with increasing productivity. Variation in the responses of aquatic plankton communities to nutrient enrichment has indicated the importance of considering not only the number of trophic levels but also the nature of the organisms within them (Leibold et al., 1997; Persson et al., 2001) and variation in the efficiency of consumers to exploit their prey (Power, 1992). Compensatory community responses may account for much of the observed variation, and dampen trophic cascades when species vulnerable to predation are replaced by less vulnerable species. For instance, primary producer biomass may increase with increasing nutrient availability when species composition shifts to inedible species, even in the presence of
efficient grazers (Mazumder, 1994; Abrams & Walters, 1996; McCauley et al., 1999). Such declines in the edibility of food with increasing primary productivity may lead to ratio-dependent interactions and proportional changes in biomass at each trophic level (Arditi & Ginzburg, 1989; Power, 1992). In shallow lakes and the littoral zones of larger lakes, spatial heterogeneity produced by submerged vegetation, coupled with movements of organisms between open water, vegetated, and benthic environments may provide important compensatory mechanisms.

Production of zooplankton has been shown to increase with temperature, while biomass accumulation is more dependent on resource availability (Shuter & Ing, 1997). Primary productivity at higher temperatures may become more controlled by nutrient turnover rate. Temperature may influence demography (Arditi & Ginzburg, 1989). Thus, with rising temperature, the inherently greater growth rate of algae compared with that of zooplankton might lead to reduced control of algal biomass by zooplankton. In addition, the threshold food requirement of zooplankton increases with water temperature and, for metabolic reasons, with increasing animal size (Lehman, 1988). This may mean a lower share of large-bodied, typically more efficient grazers in the zooplankton community at higher temperatures. Thus, the resource base may have a major role in the functioning of food webs as temperature increases, such that the cascading top-down effect of fish via zooplankton grazers on phytoplankton could become less important. In case of Wular lake that algal biomass is controlled by large crustacean grazers and the number or biomass of large grazers will increase with nutrient unless they are controlled by planktivorous fish or submerged macrophytes provide refuges against fish predation (Jeppesen et al., 1998a; Scheffer, 1999).
Therefore dredging which involves removal of emergent macrophytes will pave the way for the growth of submerged vegetation in clear waters thereby providing refuge for zooplankton against fish predation. Further major controlling factor for regulating zooplankton biomass and relative abundance of different functional groups will be fish composition instead of biomass.

**Impact of Willow Canopy Removal on Invertebrate Community**

![Diagram of Impact of Willow Canopy Removal on Invertebrate Community](image)

Figure 11: (c.f. Zukowski, and Gawne, 2006).
Impact of Willow Root Mat Removal on Invertebrate Community

Figure 12: (c.f. Courtesy: Zukowski and Gawne (2006)).
Potential Impact on Fishes

Since there is no systematic research endeavour on fish data available on the Wular lake except some preliminary and scattered reports (Appendix I). It has been general observation that Lakes with planktivorous fishes but without piscivorous often have high algal biomass. Eutrophication effects in the form of increased primary production, nuisance algal blooms, increased turbidity, oxygen depletion (anoxic zones, spatial and temporal hypoxia), pH fluctuation and hydrogen sulphide and ammonium production can cause fish kills and reduce biodiversity (Effler et al., 1990; Smith et al., 1999; Landman et al., 2005; Marti-Cardona et al., 2008). Since the Wular management plan in its essence can be treated ecologically as manipulation or hydroecological intervention and therefore have the chances of causing a regime shift, but the shift may be unstable unless other ecosystem changes such as reduced P loading are implemented as well.

The de willowing within the Wular lake can have a profound influence on fish communities through a variety of direct and indirect linkages (Pusey and Arthington 2003). Direct effects include organic input (food and habitat availability) and light and water temperature regulation (thermal regimen) (Pusey and Arthington 2003). Indirect secondary effects may potentially be realized at many different levels, and can range from ‘individual reproductive success’ which includes effects on mate recognition, egg and larval survivorship and predator avoidance, through to ‘assemblage level effects’ due to influences of riparian vegetation on habitat structure and trophic dynamics (Pusey and Arthington 2003). In addition, there is also the potential for an assortment of tertiary impacts to occur which are controlled by both the direct and indirect impacts of fish
on other organisms (Pusey and Arthington 2003) (i.e. trophic cascades; Nakano et al. 1999).

The proposed CMAP for Wular lake is likely to have an effect on fish community composition and characteristics which may be witnessed in species biomass, abundance and richness apart from both short and long term effects on fish population characteristics through an alteration of fish habitat, changes to light penetration, water temperature and food availability. Willow dominated aquatic habitats have been found to favour the growth of zooplankton and fishes by providing stable fish habitat. The findings reveal that the abundance of zooplankton associated with willow environments may provide a potential food supply to fish and that the protective dense canopy may provide an excellent diurnal resting habitat for fish communities which may feed nocturnally. Willows within aquatic ecosystems provides ideal habitat and hiding places for invertebrate and fish species besides an important role in retaining particulate organic matter (Bilby and Likens 1980), supplying substrate for the production of biomass by benthic macroinvertebrates (Benke et al. 1985), and encouraging higher levels of invertebrate species abundance and diversity (Cooper and Testa 1999) which provides increased food sources for fish communities. Willows actually add to physical habitat heterogeneity which are important to fish communities (Cooper and Testa 1999; Warren et al. 2002). The massive dredging and de willowing may therefore be associated with relatively large changes in fish numbers, biomass, and species richness due to input of organic detritus and distribution and availability of benthic drift.

The thick root mats formed by willows can play an important role in the
formation and maintenance of habitat for fish (Van Kraayenoord et al. 1995). Adult fish may use the roots as a habitat source (Pusey et al. 1998), whilst exposed roots could be used as a spawning substrate and larval habitat (Pusey et al. 2001a; 2001b). The removal of such habitat could cause short term effects on local fish assemblages if they have specific breeding requirements and a lack of vegetation to meet those requirements in the given area. But this method is subjected to question due to potential of revival by vegetative growth of willows as has been experienced in the famous Dal lake.

Shade has a role to play in habitat structure and diversity of habitats in aquatic environments. Fish utilise shade both as a refuge from predation and as an area to hide in and launch predatory attacks from (Helfman 1981). The removal of a willow canopy and the resulting light increase can have detrimental impacts on fish assemblages. Predator/prey dynamics could be shifted in favour of predator species (Van Kraayenoord et al. 1995), and at times due to increased ultraviolet (UV) B irradiation, increased egg, embryo and larval mortality may occur (Gutierrez-Rodriguez and Williamson 1999).

On the other hand, increased light concentrations and more open area from canopy removal can also shift primary production away from unicellular microalgae to filamentous green algae, therefore reducing food sources for invertebrate secondary producers (Bunn et al. 1999) and so potentially lowering food availability for fish communities. Therefore, this may lead to increased productivity by phytoplankton having more area available and also chances of colonization of exotic genera like Azolla and Salvinia as we have witnessed near Naz nallah during the dredging operation after de
willowing within the lake ecosystem.

Increased light conditions will trigger the growth of submerged macrophytes as they provide important habitats for fish and larvae (Pusey et al. 1993; Kennard 1995; Pusey et al. 1995; 1998; 2000; 2001b), valuable spawning substrates for many fish species (Pusey et al. 2001a) and acting as refuges from both predation and high-water velocity (Mittelbach 1986; Losee and Wetzel 1993). Further, the quality and quantity of macrophytes which colonise an area following de willowing within the lake will influence fish communities. Increased light conditions can lead to changes in the plant community that may have either beneficial or negative effects on fish. An example of a negative effect is the proliferation of exotic macrophytes (Pusey and Arthington 2003) which can reduce habitat diversity, alter the food-web structure and facilitate invasion and dominance of exotic fish species (Mackay et al. 2001; Pusey and Arthington 2003). Therefore, the impact of willow removal on fish communities will depend, in part, on the vegetation community that establishes at the site after de willowing.

The decrease in shady area following willow removal can lead to increased summer water temperatures and also have the ability to affect disease resistance in adult fish (Pusey and Arthington 2003), tolerance to environmental stressors, such as decreased dissolved oxygen (Llewellyn 1973; Pearson and Penridge 1992) and the embryonic development, hatching time and development of fish larvae (Llewellyn 1973). In shallow or low flow areas where the possible increase in temperature following willow removal may occur at a faster rate, especially during summer months, these effects are likely to be experienced very shortly after
disruption to the willow plantation and may prove initially quiet harsh (Van Kraayenoord et al. 1995). Long term effects associated with changes in growth, fitness and habitat selection are more likely to occur over a gradual time period and to persist in importance for a longer time as fish communities adjusts to reflect changed habitat conditions (Van Kraayenoord et al. 1995). Such effects have the potential to alter patterns of fish microhabitat use (McCauley and Huggins 1979; Matthews 1998) as well as the distribution of fish at both small and large spatial scales (Van Kraayenoord et al. 1995). These effects may also be heightened in wetlands and therefore the effect of willow removal on temperature changes should therefore be critically and continuously monitored over a period of time for observing the measurable and quantified changes in the longer run.

The immediate and direct impacts of willow removal on fish assemblages in Wular lake cannot be predicted precisely and accurately, however, considering the wealth of information available on the aspect, it can be argued with some confidence that the removal of these willows can have both long and short term impacts under certain environmental conditions (Figure 13 &14). These include reducing potential fish habitat, creating new habitat, affecting fish mate finding and predator evasion, and impacting on egg, embryo and larval growth and survivorship rates. These factors would all need serious attention and consideration while executing the major ecohydrological intervention in the form of mass de willowing and dredging in the Wular lake.
Impact of Willow Canopy Removal on Fish Community

Figure 13: (c.f. Zukowski, and Gawne, 2006).
Impact of Willow Root Mat Removal on Fish Community

Figure 14: (c.f. Zukowski, and Gawne, (2006).
Potential Impact on Macrophytes

In order to scientifically evaluate the effects of willow removal on Wular Lake, detailed long-term studies are needed. In fact, lack of any significant study specifically on the effect of willow removal on the Wular Lake so far, coupled with gaps, inconsistencies and controversies in whatever literature available on this particular subject in Wular or any other waterbodies, makes accurate predictions of the effects of willows on the Lake even more difficult. Notwithstanding these difficulties, this part of the Impact Assessment Report attempted to assess the potential impact of willow removal on macrophytes, and its likely impact on carbon balance and spread of invasive alien species in the system on the basis of secondary data and various surrogates.

On the basis of secondary data and literature review willow removal is expected to have both positive and negative impacts on the lake system, in general, and macrophytes, in particular. These potential impacts are summarised below:

- The willows growing along the boundary of the lake play an important role to act as a visible demarcation and a buffer zone between terrestrial and actual aquatic ecosystem, with an equally important role in regulating the flow of sediments through its boundaries from the catchment.
- In view of their dense canopy, willows can significantly decrease light access to nearby waters, and cause the shading and crowding effect that can potentially suppress the regeneration of existing native and indigenous understorey plants besides preventing the growth and
proliferation of aquatic macrophytes. This is because willows can compete for water, nutrients and light with native plants and can out-shade pre-existing native vegetation by ‘overtopping’. Previous studies have suggested that willow shade prevents recruitment of all but a few shade tolerant species (Frankenberg 1995; Askey-Doran et al. 1999) and there is evidence to substantiate that in plots where complete willow removal has been undertaken, herbaceous biomass has almost tripled (750 gm$^{-2}$) in contrast to control plots (260 gm$^{-2}$), probably in response to increases in light (Dulohery et al. 2000).

- On a positive note, willow stands along boundaries may act as vegetation filters and facilitate excess nutrient uptake, reduce soil erosion, provide habitat for different species above and below the water level, with a profound impact on visual characteristics of the site. Given the topography of landscape around the Wular, especially along Sadarkoot-Bandipore route, peripheral willow belts can play a pivotal role in checking the sediment load from surrounding steep mountainous terrains. This would help in maintaining the water level, water turbidity and depth characteristics that are critical for the type of macrophytic communities thriving in the system, especially along this belt.

- If managed properly along the lake margins, willows can play an effective role as a “nurse crop” for the establishment of some other economically important larger and longer-lived woody species thereby contributing to better livelihood and sustenance of local communities.

- The removal of willow plantation from within the lake system is recommended because it is going to create more open water areas and provide habitat for diverse macrophytic communities to take over.
However, regrowth of macrophytic vegetation in such areas wherefrom the willows are removed needs to be specially monitored as the invasive species are more likely to be the first colonizers in view of nutrient flushes and disturbances created by willow removal.

- In some areas that have been cleared of willows and dredged mechanically, prolific growth of black aphid mass on the leaves of some plants was observed (See photo). This change merits detailed monitoring and focused research studies, especially in relation to disturbances caused due to anthropogenic interventions.

*Nymphoides peltata* in the Wular lake prior to (left) and after (right) the willow removal and mechanical dredging efforts. Note the black aphid like parasites on the plant leaves seen only after the restoration project started.
Abundant growth of *Trapa* near Saderkot Bala in Wular Lake is used by locals for livelihood.

*Salvinia* competing with *Azolo* in Wular lake
Macrophytic association in Wular lake

A view of willow plantation along lake peripheries and inside
Likely impact of tree removal on the spread of invasive alien species and carbon balance in the system

Since willows can spread prolifically through vegetative means and are \textit{per se} highly invasive with a strong potential to dominate watercourses. By doing so these are expected to invite other invasive species to take over due the well-known process of ‘\textit{invasion meltdown’}. Even the removal of willow plantation may potentially facilitate the spread of terrestrial and aquatic introduced weeds, as they have been reported to do so by previous studies (Sattler 1993; Tait 1994; Pusey and Arthington 2003). Since removal of willow plantation from within the lake system is underway as a part of the Wular Restoration project, growth of invasive macrophytes in such areas needs is very likely due to nutrient flushes and disturbances created by willow removal, as mentioned before. The over-spread of invasive species in turn can induce a series of changes in habitat structure (Arthington et al. 1983), water quality and food-web composition (Van Kraayenoord et al. 1995; Bunn et al. 1997; 1998) of the lake. The cumulative invasions due to willow removal, if not suitably managed, can disproportionately transform the Wular lake ecosystems from being diverse and heterogeneous to almost homogenous, thereby telling upon its aesthetic and ecological value. The spatial spread of alien species, at the cost of traditionally valued native species, can be locally exacerbated by willow removal, especially in those specific patches. Moreover, an increase in the spread of invasive species and making inroads in in-stream vegetation can significantly alter the habitability of the lake system by trapping sediment and channelizing flows as reported for other systems by Bunn et al. (1998).
A challenge would be to control the competition between native and exotic vegetation following willow removal. This may be usually attempted through a variety of approaches depending on the type of vegetation. For instance, if the goal is to encourage native vegetation, the specific site preparation methods need to be used to create good beds for planting seed/seedlings/propagules of desirable native species, such as *Euryale ferox*, and suppressing the potential competing vegetation, especially in areas recently cleared of willows. Moreover, desirable macrophytic species need to be reintroduced in open water areas cleared of willows. Establishment of desired vegetation/plantations in such a scenario, and keeping at bay the undesirable invasive species, may require some weed control measures, use of bio-fertilizers, herbicides or mowing etc. as has been practiced in some systems fertilized (Hansen et al. 1993; McLeod et al. 2001).

Since the flow of water in the Wular lake is generally from various peripheries along Sadarkoot-Badipore route to the barrage created at Watlab, the uneven lake bed created by mechanical willow uprooting and dredging (Fig.3) may cause changes in water flow patterns. Since the direction of water-flow in the lake has a great bearing on the flushing of floating water weeds, such as obnoxious *Azolla cristata, Lemna minor* and *Salvinia* species, flow of water in right direction through the regulation of the barrage/gate assumes special importance. Furthermore, it is important to note that the recoverability of a particular site is related to the condition of the native vegetation present at the site and upstream of it, which provides a source of propagules for natural regeneration. There is a possibility that after the removal of willows and stock, riparian native vegetation may regenerate naturally. Notwithstanding that removal of
willows can assist in the establishment of native riparian and aquatic vegetation, there is always an equal and immediate risk of weed proliferation and of competition between native and introduced species. In the long term, as the project of Wular restoration progresses, selective removal of exotic vegetation may also ensure a higher success of native and desirable species to establish.

A view of mechanical dredging and barrage at Watlab, Sopore

So far the impact of willow removal on carbon balance is concerned, it is estimated that 2730 ha of willow plantation will yield about 32760 tons of above ground biomass per year and sequester about 20000 tons of atmospheric carbon, besides accumulating tons of nitrogen and phosphorus and other pollutants from Wular. Removal of these willows will mean removal of this significant carbon sink, and if this biomass is burnt it would add tremendous quantities of carbon into atmosphere. However, in due consultation with the Wular management authority (WUCMA), and other relevant organizations, it has been told that the willow biomass removed wouldn’t be used for burning purposes but instead for bat industry and raw material for preparing apple and other fruit boxes. We also strongly recommend the use of willow biomass for alternative
purposes rather than as fuel wood.

During the survey of willow removed areas, it was found that in many parts instead of uprooting the willows have been just cut above the ground level leaving a huge trunk and underground root biomass intact (Fig 4). The local people were found to harvest this biomass for burning purposes which shouldn’t be in any case encouraged. Moreover, it was found that some of the previously cleared willow areas have again emerged as willow gardens, and the leftover trunks in the present removal practice are likely to meet the same fate, thereby nullifying the very basic motive of willow removal.

A view of areas cleared of willows with intact trunks.

Overall, the recommendations are to (a) stop the further spread of willows and manage existing areas of willows, (b) remove willows from within the lake system to improve water area but not from peripheries, (c) manage appropriately the native vegetation wherever willows are removed, (d) find alternative uses macrophytes, and (e) gain community support in the management of willows.
Socioeconomic Aspect of the Tree Removal

Introduction

Wular lake has assumed a significant status in the regional economy of the catchment population. Not only a considerable size of the population is dependent on this lake for their livelihood and employment by way of their participation in the extraction of varied lake products but it also provides essential support for the sustenance of local primary economic sector and its allied activities. A considerable size of the lake area has been reclaimed over the period of time which has been utilized for paddy cultivation and willow plantation in response to the growing economic dependence of the catchment population on the varied products of the lake. The local economy mostly hinges on the subsistence primary economic sector and its allied activities especially animal husbandry which derive their sustenance from the varied resources of the lake. The daily extraction of the various lake products like fish, water nuts, vegetable products, fodder and fuel wood not only facilitate to meet the daily domestic requirements of the local households but also serve as a source of income to the economically weaker and marginalized sections of the catchment population. Despite the fact that the lake possess a huge potential for the development of tourism activities, but the measures are yet to be initiated to realize this tourist potential though of late a limited number of recreational sites along the shores of the lake have been developed to promote the lake related tourist activities.

However over the period of time, the wetland resources have been seriously affected by the degradation of Wular lake. The wetland
communities entirely dependent upon the lake resources such as fish, fodder, fuel and other products of the lake has drastically declined thereby affecting their livelihoods. With rapid degradation of lake water quality and absence of adequate sanitation and safe drinking water facilities, the qualities of life of these communities has eroded rapidly and have been economically marginalized and live under abject poverty.

The Comprehensive Management Action Plan (CMAP) prepared for Wular Lake has main emphasis on ecosystem conservation and livelihood security of the communities dependent on lake resources for their sustenance. Before having an evaluation of the impacts on account of the various socio-economic objectives proposed to be realised under CMAP, the demographic details of the wetland communities is produced as under:

**Demographic Profile of Wular Catchment**

Wular catchment is inhabited by 127 villages comprising of 73109 households with a population of 588346 persons. The catchment population is distributed among the three geographically distinctive zones viz; Lake shore, Foot Hills & Hills. There are about 31 villages located in the immediate vicinity of Wular lake however a significant proportion of the villages (55 per cent) fall in the foot hill zone. The distribution of villages and their demographic characteristics are shown in Fig. 15 and Table 14.

The total population of the Wular catchment is 5,88346 persons comprising 3,10263 males and 2,78083 females (Table 15). The highest population (70 per cent) is found in foot hill zone followed by 18 per cent inhabited in the vicinal area of Wular Lake. A number of urban centers like
Bandipora, Hajin and Safapora are located in the foot hill zone of the catchment. The catchment has got a sex ratio of 896 which is higher than the state average sex ratio of 888. Sex ratio varies from 912 (highest) in Foot Hill Zone to 830 in the Hill Zone whereas lakeshore settlements have a sex ratio of 879. The literacy rate is comparatively higher (58.89) in Foot Hill Zone and lowest (35.55) in Hill Zone. Whereas the average literacy rate for the catchment is 46.62 percent which is less than State’s average literacy rate of 56.35 per cent. The majority of people are of in the productive age group (64.3 per cent) followed by the Young (25.3%) and the Old age (13.2%).

Table 14: Wular Catchment: Number of villages & Households

<table>
<thead>
<tr>
<th>Catchment Division</th>
<th>No. of Villages</th>
<th>No. of Households</th>
</tr>
</thead>
<tbody>
<tr>
<td>LakeShore</td>
<td>31</td>
<td>13405</td>
</tr>
<tr>
<td>Foot Hills</td>
<td>70</td>
<td>50102</td>
</tr>
<tr>
<td>Hills</td>
<td>26</td>
<td>9605</td>
</tr>
<tr>
<td>Wular Catchment</td>
<td>127</td>
<td>73109</td>
</tr>
</tbody>
</table>

Source: Compiled from Census of India, 2011 & Sample Survey, 2012

Table 15: Demographic Profile of Wular Catchment

<table>
<thead>
<tr>
<th>Catchment</th>
<th>Population (persons)</th>
<th>Sex Ratio</th>
<th>Literacy (%)</th>
<th>Age Structure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total</td>
<td>Male</td>
<td>Female</td>
<td>% of total Population</td>
</tr>
<tr>
<td>Lakeshore</td>
<td>105902</td>
<td>56370</td>
<td>49532</td>
<td>25.2 63.5 11.3</td>
</tr>
<tr>
<td>Foot Hills</td>
<td>411842</td>
<td>215320</td>
<td>196522</td>
<td>23.7 68.1 13.2</td>
</tr>
<tr>
<td>Hills</td>
<td>70604</td>
<td>38573</td>
<td>32029</td>
<td>27    61.3 11.7</td>
</tr>
<tr>
<td>Wular Catchment</td>
<td>588346</td>
<td>310263</td>
<td>278083</td>
<td>25.3 64.3 12.06</td>
</tr>
</tbody>
</table>

Source: Compiled from Census of India, 2011; Sample Survey, 2012
Occupational Structure

The occupational structure of Wular catchment as given in Table, 16 is dominated by primary sector (64.83.5%) while as the tertiary sector is also significant (22.96 %). The secondary sector has a least proportion (12.13%). The dominant primary economic activities are mostly lake dependent which includes extraction of fish and aquatic vegetation especially in the lake shore settlements. The foothill communities have a
diversified livelihood portfolio. While agriculture and horticulture remain the basic source of income to the people living in foot hills some draws sustenance on dairying, artisanal crafts and other activities. Communities living in the hills are based on catchment resources and sheep rearing. The primary occupation of the hill communities is collection of firewood and charcoal, which is the main source of energy for the entire valley. Illegal timber felling also provides a rich source of income to the communities.

Table 16: Occupational structure of working population

<table>
<thead>
<tr>
<th>Watershed</th>
<th>Population</th>
<th>Total Workers %</th>
<th>Occupational Structure % of total Working Population</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
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<td>63.7</td>
</tr>
<tr>
<td>Foot Hills</td>
<td>411842</td>
<td>32.8</td>
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</tr>
<tr>
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<td>70602</td>
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<td>Wular Catchment</td>
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Source: Sample Survey, 2012

Comprehensive Management Action Plan (CMAP) – Socio-Economic Impacts

The Comprehensive Management Action Plan (CMAP) focuses mostly on restoration of Wular Lake for ecosystem conservation and livelihood security of the communities dependent on the lake resources for sustenance. The plan emphasizes on ecotourism as a potential tool to conserve lake and its rich biodiversity while providing economic incentives to the local communities. A number of additional /alternative income generation programmes have been proposed for the sustained economic development of the region with the focus on social equity and gender sensitivity. The plan is based on adoption of a community based
approach to resource management with facilitation from government agencies and scientific institutions in terms of technical and financial resources. The CMAP emphasizes on improving the livelihoods of socially and economically weaker sections of the society which are entirely dependent on wetland for their livelihoods. The CMAP has a special focus on poverty reduction through sustainable resource development and is in line with the approach followed by planning commissions in its 10th & 11th five year plans. A critical analysis and evaluation of ecological and socio-economic features associated with the Wular lake have provided the rational for identification of objectives and the benefits that would lead through the implementation of CMAP. The analysis has been carried out with the help of rapid assessments, extensive Participatory Rural Appraisal (PRA) exercises and socio economic surveys in selective villages within the valley as well as in the hill areas to identify the critical ecological issues, socioeconomic conditions of the communities, resource linkage and their needs and aspirations. However the information collected is deficient in many respects to support the proper management planning for the realization of various objectives formulated under CMAP. A comprehensive socioeconomic profiling of all the households along with household and non-household asset structure of the catchment population needs to be carried out for the effective implementation of the various strategies proposed under CMAP in order to realize their desired impacts and develop basis for sustainable resource management.
Availability of Sources of Domestic Energy

The willow plantation within and adjoining lake area serve not only as a major source of domestic energy requirements but also contributes to the local employment and source of household income to the economically weaker and disadvantageous sections of the lake population. As the CMAP proposes removal of 27.30 sq. km of plantation area, it envisages to provide 0.33 Mcum of small timber, 0.55 Mcum of firewood and 2200 Cum of leaf fodder to hill households through restocking of 7436 ha of degraded forests and agro-forestry in 1,000 ha of croplands/homesteads. Besides this availability of 800 MT fuel wood to lakeshore households through development of 1500 ha of village woodlots is also proposed to augment the sources of domestic energy requirements. However the proposed compensatory measures are of long term nature which may require a period of more than ten years to yield the fuel wood products to be used by the local population. Secondly there could be a number of impediments in the creation of village woodlots on commons, Kahcharais and group lands as majority of these have been encroached by the local population and have converted them in different land uses for serving their daily requirements. Therefore an estimation of average annual fuel wood based energy consumption of lake population needs to be worked out in order to meet these requirements through various appropriate short term measures.
Reduced Fuel Wood Consumption

There is an urgent need of reducing the fuel wood consumption as it will not only facilitate to improve the health and hygiene of lake population but will reduce the pressure of fuel wood harvest on forests of the lake catchment. The CAMP proposes to reduce harvest of fuel wood from forests by 60 per cent through creation of village woodlots in 1500 ha area covering 75 per cent settlements and provision of smoke less hearths to 75 per cent households living in the Wular catchment. In addition, construction of mini hydel- power project is also proposed in Erin catchment. However no estimation about the existing magnitude of fuel wood consumption of the population living in the lake catchment has been worked out in the CMAP. The proposed measures outlined in CMAP may provide alternative and efficient fuel wood resources for the wetland dependant population to reduce the pressure on degraded forest resources of the catchment.

Livelihood Improvement & Diversification

The lake population is characterized by a high incidence of poverty as it is heavily dependent on the lake resources with limited livelihood opportunities. The declining productivity of lake resources and shrinking yields demand for a dire need for improvement and diversification of livelihood of lake population. The CMAP envisages reducing the poverty below 50 per cent through improvements and diversification of livelihoods. Additional and alternate income generation sources are important means for diversifying livelihoods and reduce vulnerability to natural changes, presently in the form of reduction of lake resources. These
ventures are proposed to be operated as community micro enterprise as self help groups, with inbuilt mechanisms for supporting credit needs as well as achieving financial and technical self reliance through investment into infrastructure and skill base. A number of micro-enterprises for hill communities like, Mushroom cultivation, Medicinal Plants, Sericulture, Apiculture, Minor Forest Produce: Whereas micro enterprise for lake shore communities linked with fisheries and aquatic vegetation have been proposed. Additionally the following activities have also been suggested to be taken up for livelihood improvement of the lakeshore communities which include, Poultry Development, Apiculture, Natural dyes & Floriculture. An Increase in average household incomes by 21% over the present and Occupational diversification through alternate sources of income to 25% hill and 20% lakeshore households has also been proposed. However the measures suggested for livelihood improvement and occupation diversification are expected to meet with limited success. The establishment of micro-enterprises for hill communities in activities like medicinal plants, sericulture, apiculture etc., may not prove economically viable because of limited availability of these resources in the forest areas of the catchment. Secondly there is a huge deficiency of a well institutionalised micro credit mechanism and with a supportive capacity building apparatus for the successful operation of these enterprises. Thirdly given the socio-economically stratified nature of catchment population, the CMAP does not mention the population target based approach for initiating these programmes regarding the livelihood improvement and diversification.
Enhancement of Fish Capture

A significant proportion of the working population is economically marginalized one and is mostly dependent on primary sector and its allied activities related to the ecosystem services of Wular lake. Economically the Lake plays an important role in providing livelihood to a large number of families involved in fishing for which it is famous in the whole Valley. As per the estimates of CMAP, capture fishing is the main occupation of 2,331 households from which there are some 2,621 active fishers while the rest are engaged in trade and/or limited value addition processes including salting and drying. Analysis of the resource mapping trends reported in CMAP indicated a steep decline in the fish catch over the last fifty years due to the degradation of lake ecosystem. The total catch as extrapolated from the catch records from the surveyed villages has declined from 10,544 MT to 1,476 MT. With a threefold increase in population of households dependant on fisheries, and decline in overall catch, the per capita catch has gone down by 20 times. The existing average annual household income from fisheries is therefore hardly sufficient to sustain an average household. Economic status of the fisher households is further constrained by lack of access to formal credit mechanism.

The CMAP envisages enhancing the annual capture fisheries production by 800 MT and culture fish yield by 1300 MT leading to an increase in annual income by Rs. 34,000 for 2,300 fisher households. This target is supposedly to be achieved through a series of interventions which includes community led management of lake fisheries and aquatic vegetation resources through establishment and operationalization of 24 cooperatives. In addition, the construction and operationalization of three fish seed
farms exclusively for culture of *Schizothorax* fingerlings within Madhumati and Erin catchment areas to revive the indigenous fish fauna and to augment fish diversity in Wular. The Extensive stocking of Mahseer (*Tor pectora*) through the fish seeds available from the Mahseer fish farm of State Fisheries Department being established at Bela (Uri) is also proposed for this purpose. Enhancing auto recruitment through protection of breeding and spawning areas and construction and operationalization of 5 community owned hatcheries cum rearing facilities and introduction of integrated fish farming techniques (e.g. fish cum duck farming) to promote effective use of village ponds and reduce pressure on lake fisheries is also part of the proposed measures for enhancement of fish catch.

The CMAP also proposes a series of measures to be induced through changes in hydrological regime of lake aimed to increase the water levels to enhance capture fisheries.

However the CMAP also reports that the Information on Wular fisheries is inadequate and fragmented and inadequate to support systematic management planning. There is absence of systematic inventorization and assessment of overall species richness and diversity.

The proposed measures under CMAP are not expected to meet optimum impacts as the series of hydrological interventions will induce the destabilizing process which could have impacts on the lake fish habitat even though for a shorter period of time. However the introduction integrated fish farming backed by availability of micro-credit facility and extension services are expected to yield a series of economic dividends including enhancement of fish catch.
Enhanced Access to Fisheries Infrastructure

The fisheries infrastructure is not only traditional but also grossly inadequate and deficient one. The CMAP envisages providing enhanced access to fisheries infrastructure (landing, storage and processing facilities) to 2,200 fisher households through strengthening of 9 landing centers and creation of 4 fish processing and valuing addition units around Wular Lake. A series of measures including collectivizing fish landing through strengthening of existing landing centres through creation of appropriate infrastructure and enhancing capacity, provision of improvised fishing crafts and gears to the fishers to optimize effort, enhancing stocking capacity and prevention of distress selling of fish through restructuring existing fish tanks in a number of fisher village, enhancing shelf life of fish through provision of ice plants at main landing centres in order to increase the shelf life of the fish. In addition to this, the provision of insulated vans to enable transportation of fish from the landing centres to the markets and enabling value addition of fisheries through establishment of modern fish processing plant in order to optimise the economic returns. All these measures are expected to have positive impact on the fisher community.

Enhanced Sources of Income

The CMAP envisages enhanced income for 600 hill and 8,200 lakeshore households through operationalization of micro-enterprise based on sustainable use of locally available natural resources. Several plant species are utilized for mat manufacturing, basket weaving and other products. The yield from trapa cultivation is further processes and transported through a
chain of contractors and finally sold in the markets of Srinagar and other towns. It is proposed to organize ten micro enterprise units in lakeshore villages based on aquatic vegetation. Each of the micro enterprise unit shall be registered as a society and invest a part of the proceeds into group capital, to be used for credit–savings operations. The units shall be federated and linked with the established marketing channels viz State Craft Emporiums, Cottage Industries Exposition etc. However there is a need to identify the backward and forward linkages of these micro-enterprises to develop them into micro–complexes in order to their optimise economic returns and ensure the maximum utilization of locally available resources.

**Improvements in Quality of Life**

The Wular catchment is socially backward and economically marginalized one. The area lacks the basic civic amenities and the residential environment is poor and unhygienic resulting in a low quality of life of people. Lakeshore communities in particular have limited access to social infrastructure, particularly adequate drinking water and sanitation facilities. High incidence of water borne diseases also leads to more frequent loss of working days and morbidity within the communities. This significantly reduces the opportunity for, ensuring safer living and better quality of life. The CMAP proposes a series of measures to improve the quality of life. These include the provision of access to safe drinking water and sanitation facilities to 18,600 households in lakeshore villages by construction of 100 units of pond. The other measure to improve the quality of in the area is to strengthening rural markets In order to enhance economic returns of the agroforestry / micro enterprise produce to the hill communities, though
better communication and infrastructure facilities. These facilities shall be
developed through the existing market / trader associations. The activities
to be taken up are, development of approach roads, construction of zero
energy cooling chambers for storage of agri / horti produce and
construction of market sheds and auction halls. The other measures
proposed to improve quality of life include water quality improvement to
get through the Augmenting pollution abatement programme with a focus
on interception and treatment of sewage, solid waste management in areas
in immediate proximity of river, which could include collection, disposal
and management of solid waste and sewage management in urban
peripheral towns of Wular, community based solid waste management
systems, Low cost sanitation in peripheral villages. There are presently
about 15 per cent of 21,516 households residing in the 44 villages situated
on Wular periphery towards north and eastern sides having access to
adequate sanitation facilities. It is therefore proposed that sewage
generated from rest of the villages without sanitation facilities and
scattered in the Madhumati and Erin catchment area shall be intercepted
using low cost sanitation. The series of measures under CMAP proposed to
be initiated for improving the quality of life of catchment population weigh
ambitious given their budgetary provisions. A prioritization scheme of area
and works needs to be devised in order to realise the achievable targets.
And at the same time, the efforts of coordination need to be taken up with
different central and state agencies/departments as most of these measures
also form a part of the various central and state government sponsored
schemes.
Ecotourism Development

Despite the huge potential for tourism, Wular lake has not received the desired attention for the development of its untapped tourist potential. The lake is endowed with diverse natural tourist products with an immense potential to turn it into one of the leading regional tourist hubs. Development of sound ecotourism infrastructure need to be carefully established to ensure minimal impacts on the environment while at the same time maximizing opportunities for the visitors to enjoy the wetland and their biodiversity. Therefore there is a need for development of ecotourism in and around Wular Lake for awareness generation and providing economic benefits to the local communities. At present there are no facilities and these need to be developed taking into consideration the environmental factors and tourist carrying capacity of different areas.

The CMAP proposes development of a comprehensive ecotourism plan with a detailed zoning plan of the lake, associated marshes and catchment areas. The tourist activities proposed to be developed are for bird watching, water sports, fish angling to enjoy its natural beauty. The sites of attraction in and around Wular are proposed to be enhanced and equipped with facilities for the visitors to stay for longer duration. Interpretation centres developed at key spots for generating awareness about biodiversity and ecological significance of the Lake. Development of key sites for bird watching and provide facilities to observe birds at different spots, developing board walks to have closer look at marshes and nature, construction of bird hides at key points, Watch towers built strategically to have close view of Wular Lake and its marshes.

The CMAP also proposes tourist infrastructure development which
constitutes the backbone of the tourism industry. The provision of easy access, clean accommodation, convenient local travel, and opportunities for relaxation and entertainment determine the popularity of a tourist destination are among the infrastructural facilitates proposed to be established for ecotourism development.

The development of ecotourism activities in and around the Wular lake would not only open a host of employment opportunities for the wetland dependent communities but would also induce a multiplier effect on the tourist ancillary sectors like transport, hotel industry, handicrafts, agriculture products and local market and the skilled and semi skilled labour classes. The tourism related initiatives would prove a long way in ameliorating the poverty of wetland dependent communities. However it needs to be ensured that the maximum benefits of the tourism related activity should reach mostly to the socially backward and marginalized sections of the wetland dependent community through their induced mass and community participation in carrying and managing the ecotourism activities in and around the wetland.

Trapa provides source of livelihood for adjoining population
Sand mining is one of the occupations of lake dwellers

Faecal matter from dry latrines directly entering the stream near Wular lake

Discussion with local population regarding CMAP
The restoration of the Wullar lake is a long-term initiative which could be accomplished in a phased manner as has been planned by the Lake management authorities. The actions that are planned during different phases need to be monitored and evaluated for taking the corrective measures for realizing maximal benefits for the lake restoration. Accordingly, it is suggested that the Lake Management Authorities should put in place, on priority, adequate network of observation stations for monitoring, in time and space, the environmental, hydrological, meteorological, hydro-biological, vegetation and atmospheric processes and phenomena in the lake and its catchment. The instrumentation to measure and monitor these processes and phenomena have to be appropriately stationed at locations in order to optimally understand the impacts of various influencing factors on the Lake environment. The proposal of the Lake management authorities for setting up the labs and testing sites is appreciable but these labs need to be adequately equipped for analysis of the measured and sampled data. The data that acquired from these stations and lab analysis shall go a long way in understanding and evaluating the impacts of the proposed project interventions on the short- and long-term basis. Further, this data shall provide very valuable information and knowledge for developing a perspective and vision action plan for the conservation of Wullar lake.
The lake management authorities shall, on priority basis, commission a research study through a reputed research/academic institutes to investigate the causal factors responsible for the deterioration of the lake environment during the last 100 years. In absence of such a research study, the measures shall continue to be adhoc with very minimal influences on arresting the deterioration of the Wular.

A set of Best Management Practices (BMP) should be promoted in the basin for the long-term control of the nutrient loading to the lake from the immediate catchment. These BMP could include vegetated buffers, crop rotations, construction of artificial wetlands, rejuvenation of springs and wetlands, water quality improvement measures, crop residual management, pastureland management, minimal use of fertilizers and nutrient management for water quality improvement.

Dredging the lake wholesome and hotchpotch without these scientific considerations could be prohibitively expensive in terms of the ecological and economic costs. The choice about the type of the dredging equipment is very important. It is recommended to use JPCs and Bulldozers for dredging in dry areas and hydraulic dredging (Watermasters) in lake waters.

The lake authorities should devise a proper sediment disposal mechanism so that these sediments, once dredged, are properly utilized and fixed in nature so they don’t find its easy way back into the lake through various land and water surface processes.

It is also suggested to built settling basins on the pattern of Dal lake on all the major inlets of the Wular lake. The settling basins will not only check the pollution but will also prevent the lake from siltation.
The CMAP proposes removal of about 27.63 sq km of plantations, but on the other hand area to be dredged under willow plantation is 7.47 sq km only. It is recommended to include all the areas (Willow removal areas and drylands within the lake boundary) in the dredging plan which will not only increase the water holding capacity of the lake further but will also help in reducing the impacts on water quality.

The lake authorities need to have the sediment cores of the lake analyzed by a qualified expert and also initiate bathymetric surveys to determine the appropriate depth and location of the dredging so that the optimal benefits of the lake dredging are achieved effectively in the long run.

It is recommended that the willow removal should be only restricted within the lake boundary (demarcated by bund), while leaving the buffer zone intact. In fact buffer zone can be used for willow plantation wherever, it is not present considering the importance of willows to filter the nutrients, trapping of sediments, erosion control and stabilization of bunds. However, continuous monitoring is needed to check their invasion within the lake boundary.

Regrowth from stumps, pieces of stems or seeds and roots will need to be followed up with monitoring and further control for 3–5 years after the initial effort. Remove trees that could cause problems if they become snared elsewhere by floods. Look for the spread of any new willows and follow up with substantial re-assessments at least every five years.

The removal of willow plantation from within the lake system is recommended because it is going to create more open water areas
and provide habitat for diverse macrophytic communities to take over. However, regrowth of macrophytic vegetation in such areas wherefrom the willows are removed needs to be specially monitored as the invasive species are more likely to be the first colonizers in view of nutrient flushes and disturbances created by willow removal.

- We also strongly recommend the use of willow biomass for alternative purposes rather than as fuel wood.
- Willow help in reducing the flow of water and removal of willow will increase the bank erosion, which could lead to inflow of sediments, nutrients, and soil particles into the lake causing siltation and turbidity. Restoring buffer strips on the margins of cropland and streambanks, as well as shoreline buffer zones are important steps in protecting water quality and improving shoreline and littoral habitat.
- Critical habitat surveys and reports should be completed on lakes and streams where habitat, native plant beds, and public rights features need to be inventoried and management recommendations developed.
- All resource agency staff, recreational users and the public need to remain vigilant to prevent the spread of both aquatic and terrestrial invasive species.
- Continue long-term monitoring of fisheries and habitat to track trends and develop further lake and fisheries management recommendations.
- It is important to make communities and stakeholders living in the catchment of the Wullar a part of the conservation plan. In this regard, the proposed initiatives by the Wullar Lake Development Authority are
timely and appreciated. It would be rewarding, if, the lake authorities devise a concerted strategy for sharing knowledge and wisdom with the local communities in the study area through short term training courses, field campaigns, symposia, workshops and other face to face contacts. The schoolteachers, students, panchayats, eco-clubs, NGO’s, line agencies, village conservation committees, and other segments of the civil society should be the target audience of these educational and awareness proposed activities. These face-to-face contacts would help in building a trust with the stakeholders and other interested groups whose cooperation and active participation is a key to the success of implementing the approved conservation plans. The qualitative information about the needs, perceptions, concerns, and local knowledge of the stakeholder communities, gathered during the public contact programs, should be assimilated into the conservation plans to fine tune and refine the plans.

- It will be also very rewarding, if the lake authorities would devise a strategy for involving eco-clubs, high school students and teachers in the collection of field data about biophysical and socio-economic aspects (environmental variables, population, health, industries, public perception etc.). These groups of prospective volunteers should be imparted training in collecting scientifically the quantitative and qualitative information about the different aspects of the environment. They should be encouraged to do the preliminary analysis of the collected data. For that, each participating entity (school, club, group, panchayat) should be provided with some incentives such as a computer or other logistic support to increase
their interest and association with the initiative. The involvement of the local students in the conservation of the lake would boast the local community participation in the later stages of the initiative. Further, the exercise is of tremendous education importance to these students and other groups and would help in furthering the education and knowledge about the resources and environmental issues within the local communities. Efforts should be made to give official credits to these students for their involvement in the lake conservation measures.

References
## Appendix I

<table>
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<tr>
<th>S.No.</th>
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<th>Main findings</th>
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<tr>
<td>1.</td>
<td>Javaid Ahmad Shah and Ashok K. Pandit.</td>
<td>Physico-Chemical Characteristics Of Water In Wular Lake –A Ramsar Site In Kashmir Himalaya</td>
<td><em>International Journal of Geology, Earth and Environmental Sciences, 2 (2):257-265, 2012.</em></td>
<td>Among the various parameters recorded, the overall surface water temperature ranged from 2.2°C to 32.4°C; transparency from 0.2 m to 2.2 m; depth from 0.3 m to 5.5 m; pH from 7 to 8.8; dissolved oxygen from 3.4 mg/L to 11.5 mg/L; total alkalinity from 47mg/L to 257 mg/L; free CO2 from 8 mg/L to 28mg/L; chloride from 8.4 mg/L to 29 mg/L; ammonical nitrogen from 49 μg/L to 542 μg/L; nitrate nitrogen from 146 μg/L to 483 μg/L, orthophosphate 13.0 μg/L to 36 μg/L and total phosphate from 102 μg/L to 297 μg/L. The high values of the physico-chemical parameters (total phosphorus, orthophosphate phosphorus and nitrate-nitrogen) of water obtained in the present study sites revealed the eutrophic status of the lake.</td>
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<td>2.</td>
<td>Javaid Ahmad Shah and Ashok K. Pandit</td>
<td>Relation Between Physico-chemical Limnology and Crustacean Community in Wular lake of Kashmir Himalaya</td>
<td>Pakistan Journal of Biological Sciences, 16(19):976-983, 2013.</td>
<td>Total number of recorded species of crustaceans were 42 belonging to three different groups namely cladocera(23), copepod(16) and ostracoda (3). From the study it can be inferred that diversity and distribution of crustaceans in the Wular lake is controlled by a combination of abiotic (temperature, pH, depth and alkalinity) as well as biotic factors including food availability, predation, alteration of parthenogenetic and gametogenetic reproduction modes.</td>
</tr>
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<td>3.</td>
<td>Javaid Ahmad Shah and Ashok K. Pandit</td>
<td>Some crustacean zooplankton of Wular lake in Kashmir Himalaya</td>
<td>African Journal of Environmental Science and Technology, 7(5):329-335, 2013.</td>
<td>A pictorial key was developed from the taxonomic survey of crustacean zooplankton collected from Wular lake of Kashmir. Thirty-six (36) pictures of 25 species of crustacean zooplankton, out of which 21 represented 16 Cladocera taxa belonging to Chyadoridae (Alona affinis, A. rectangula and A. monacantha, Chydrorus sphaericus and C. ovalis), Daphnidae (Daphnia magna, D. catawba, D. magna, D. pulex; D. rosea, D. galeata, D. retrocurva and Moinodaphnia), Polyphemidae (Polyphemus pediculus) and Sididae (Sida crystallina) and 15 pictures of Copepoda belonged to 9 species being represented by three families viz Cyclopidae (Cyclops scutifer, C. bicuspidatus, C. vernalis, C. panamensis, Eucyclops agilis, Megacyclops viridis), Canthocamptidae (Bryocamptus hiemalis) and Diaptomidae (Diaptomus sp.).</td>
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<td>4.</td>
<td>Javaid Ahmad Shah, Ashok K. Pandit and G. Mustafa Shah</td>
<td>Distribution, diversity and abundance of copepod zooplankton of Wular Lake, Kashmir Himalaya</td>
<td><em>Journal of Ecology and the Natural Environment, 5</em>(2): 24-29, 2013.</td>
<td>A total of 16 species of copepods belonging to three families (Cyclopoida with 12 species, Calanoida and Harpacticoida with two species each) were identified. Cyclopoids predominated over calanoids in the study. The most abundant taxa in order of dominance were <em>Cyclops bicolor</em>, <em>Bryocamptus nivalis</em>, <em>Eucyclops agilis</em> and <em>Cyclops latipes</em> and other species observed were <em>Acanthocyclops bicuspidatus</em>, <em>C. bicolor</em>, <em>Cyclops bisetosus</em>, <em>Cyclops bicuspidatus</em>, <em>C. panamensis</em>, <em>Cyclops scutifer</em>, <em>Cyclops vicinus</em>, <em>C. latipes</em>, <em>E. agilis</em>, <em>Bryocamptus minutus</em>, <em>B. nivalis</em>, <em>Diaptomus sp.</em> and <em>Diaptomus virginiensis</em>.</td>
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<td>5.</td>
<td>Javaid Ahmad Shah and Ashok K. Pandit</td>
<td>SEASONAL SUCCESSION OF CRUSTACEAN ZOOPLANKTON IN WULAR LAKE OF THE KASHMIR HIMALAYA</td>
<td>Arch. Biol. Sci., Belgrade, 65 (3):1063-1068, 2013.</td>
<td>A total of 42 crustacean taxa belonging to Cladocera (23), Copepoda (16) and Ostracoda (3) were identified at different sampling sites. Among the crustaceans, Cladocera was numerically the most dominant group followed by Copepoda. On an average basis total crustacean density ranged from 416 ind./l in winter to 1567.6 ind./l in summer. On the basis of Sorensen’s Similarity Index, study sites IV and V showed close similarity (88.13%). A succession pattern where cladocerans dominate during the spring and summer seasons and Copepoda in autumn and summer, was found in the study. However a low crustacean density was obtained during winter.</td>
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<td>6.</td>
<td>Naseer Ahmad Dar, Aadil Hamid, Bashir Ahmad Ganai, Sami Ullah Bhat and Ashok Kumar Pandit.</td>
<td><strong>Primary Production Dynamics of Two Dominant Macrophytes in Wular Lake, a Ramsar Site in Kashmir Himalaya.</strong></td>
<td><em>Ecologia Balkanica, 4(2): 77-83, 2012.</em></td>
<td>It was concluded from the study that the investigated aquatic ecosystem is dominated by macrophytes, one floating (<em>Nymphoides peltatum</em>) and another submerged (<em>Ceratophyllum demersum</em>). These plant species were characterized by uneven biomass during the vegetation period, which is brought about by the ambient climatic conditions and the trophic state of the investigated aquatic ecosystem. The enormous biomass which they form by the end of the vegetation period causes secondary pollution of the lake, which directly affects the trophic level of the ecosystem by accelerating the eutrophication process in this lake. Therefore it is necessary to monitor and control their growth and development. The results of the present study have implications for efficient eco-restoration of the lake ecosystem through scientific management of macrophytic vegetation.</td>
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<td>7.</td>
<td>Altaf H. Ganai, Saltanat Parveen, Asif A. Khan and Maryam H.</td>
<td><strong>Phytoplankton diversity at Watlab Ghat in Wular Lake, Kashmir.</strong></td>
<td><em>Journal of Ecology and the Natural Environment, 2(8): 140-146, 2010.</em></td>
<td>A total of 64 phytoplankton spp. were identified. Bacillariophyceae was found to be the most dominant group at the selected site. The population density of bacillariophyceae varied from a minimum of 32 No./ml in the month of June, 2007 to a maximum of 417 No./ml in the month of January, 2008. The most abundant species in terms of population density were <em>Amphora spp.</em>,</td>
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</table>
Cyclotella spp., Longissima elongatum, Navicula spp. and Nitzchia spp. Chlorophyceae formed the second most dominant group of phytoplankton with Chlorella spp., Pediastrum spp., Spirogyra spp. and Volvox spp. as the most abundant species. The number of chlorophyceae varied from minimum of 25 No./ml during December, 2007 and February 2008 to a maximum of 222 No./ml in May, 2007. Amongst myxophyceae (cyanophyceae), Anabaena spp. with population density of 93 No. /ml was found to be the most dominant spp. at the selected site. Euglenophyceae formed the least represented group of phytoplankton which showed the peak population in spring. In general, phytoplankton in present study depicted bimodal peak spring and winter.
| 8. | M.R.D. Kundangar, S.G. Sarwar and Javid Hussain. | Zooplankton population and nutrient dynamics of wetlands of Wular lake, Kashmir, India. | Environment and Biodiversity: In the context of South Asia, 1996, pp.128-134. Eds: P.K. Jha, G.P.S. Ghimire, S.B. Karmacharya, S.R. Baral and P. Lacou. Publisher: Ecological Society (Ecos), Kathmandu, Nepal. | Fifty species of zooplankton were recorded at the investigated sites of the Wular lake, of which 37 belonged to rotifer, 9 to cladocera and 4 to copepoda. The predominant species of zooplankters in the Wular lake were: Keratella cochlearis, Polyarthra vulgaris, Ascomorpha sp, Bronchionus quadridentata, Filinia longiseta, Monostyla bulla, Cephalodella sp, and Anuraeopsis fissa (Rotifera); Alona costata, Chydorus sphaericus, Bosmina longirostris (Cladocera); Cyclops seutifer, Paracyclops affinis and nauplii larvae (Copepoda). The authors attribute the dominance of rotifers in the Wular lake to the influence of artificial eutrophication. |

| 9. | Rumysa Khaliq, Sharique A. Ali, Tariq Zafar, Mohd. Farooq, Bilal A. and Pinky Kaur. | Physico-Chemical Status of Wular Lake in Kashmir. | Journal of Chemical, Biological and Physical Sciences, 3(1):631-636, 2012. | The physico-chemical parameters of Wular Lake studied included the atmospheric temperature (recorded between 31°C to 7°C), water transparency values were (ranged from 0.9 m to 0.1 m), hydrogen ion concentration (ranged between 8.7 to 7.1), alkalinity (varies from 224 mg/l to 53 mg/l), dissolved oxygen (varied from 10.8 mg/l to 2.7 mg/l), chloride (ranged between 33 mg/l to 14 mg/l), calcium hardness (ranged between 54 mg/l to 23 mg/l) and magnesium content (ranged from 37.1 mg/l to 15 mg/l). Low content of dissolved oxygen indicated a sign of organic pollution. |
| 10 | C.L. Trisal, Robson Ivan and M. R. D. Kundangar | Ramsar Sites of India WULAR LAKE of Jammu and Kashmir | RAMSAR SITES OF INDIA-1994 | A total 82 species of phytoplankton are reported in which 53 belong to Bacillariophyceae, 21 to Chlorophyceae, 5 to Cyanophyceae, 2 Euglenophyceae and 1 to Chrysophyceae. Dominant species found include Synedra ulna, Navicula sp., Gomphonema olivaceum, Diatom elongatum, Amphora sp., Cocconeis placentula, Fragillaria vaucheriae, Cymbella sp., Closteridium sp., Scenedesmus sp., Euglena sp., Dinobryon sp., Oscillatoria sp., and Chrococcus sp. |
| 12 | Altaf H. Ganai and Saltanat Parveen | Effect of physico-chemical conditions on the structure and composition of the phytoplankton community in Wular Lake at Lankrishipora, Kashmir | International Journal of Biodiversity and Conservation.2014 6(1):71-84. | A total of 64 phytoplankton belonging to bacillariophyceae, chlorophyceae, cyanophyceae and euglenophyceae were identified. Phytoplankton in general, showed two growth periods, one in spring and other in winter. A clear dominance of bacillariophyceae over chlorophyceae, cyanophyceae and euglenophyceae was observed throughout the study period while Euglenophyceae formed the least represented group of phytoplankton with peak population in spring. Canonical correspondence analysis (CCA) showed that the most important factors affecting phytoplankton distribution are water temperature, CO2, chloride, transparency, TDS, alkalinity and dissolved oxygen. |