Mekong River Commission

Japan International
Cooperation Agency

THE STUDY ON HYDRO-METEOROLOGICAL MONITORING FOR WATER QUANTITY RULES IN MEKONG RIVER BASIN

FINAL REPORT

VOLUME II SUPPORTING REPORT (2/2)

March 2004

CTI Engineering International Co., Ltd.

NIPPON KOEI Co., Ltd.

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COMPOSITION OF FINAL REPORT

VOLUME I	**:**	**MAIN REPORT**
VOLUME II	**:**	**SUPPORTING REPORT (1/2)**
PAPER I	**:**	**IMPROVEMENT OF HYDROLOGICAL STATIONS**
PAPER II	**:**	**GAP FILLING OF RAINFALL DATA**
PAPER III	**:**	**HYDROLOGICAL MONITORING**
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MAINTENANCE OF FLOWS ON THE MEKONG MAINSTREAM

FINAL REPORT

MARCH 2004

WUP-JICA TEAM

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INTRODUCTION

1. On 5 April 1995, the governments of the four riparian countries in the Lower Mekong River Basin; namely, Cambodia, Lao PDR, Thailand and Vietnam, signed a historic "Agreement on the Cooperation for the Sustainable Development of the Mekong River Basin." The Agreement set a new mandate for the organization "to cooperate in all fields of sustainable development, utilization, management and conservation of the water and related resources of the Mekong River Basin."

2. The Water Utilisation Programme (WUP) is being undertaken to help the member states of the Mekong River Commission (MRC) to implement key elements of the Agreement on the cooperation for the sustainable development of the Mekong basin. The WUP aims at formulation of appropriate "Water Utilization Rules" to ensure reasonable and equitable use of the Mekong waters and related resources that are addressed in the Agreement. The WUP aims at putting the related articles into practice, and there are now five sets of Rules being formulated, as follows:

Category	Rule
Procedural Rules	1. Procedures for Data and Information Exchange and Sharing (approved in July 2001)
	2. Procedures for Water Use Monitoring (approved in November 2003)
	3. Procedures for Notification, Prior Consultation and Agreement (approved in November 2003)
Technical Rules	4. Rules for the Maintenance of Flows on the Mainstream (to be approved by the end of 2004)
	5. Rules for Water Quality (to be approved by the end of 2005)

3. One of the main objectives of the WUP-JICA Study is to provide MRC with technical assistance in the drafting process of preparation of the Rules for the Maintenance of Flows on the Mainstream (so-called the Water Quantity Rules). The purpose of this work is to provide technical supplementary information for supporting framework procedures of the rule preparation with the main focus on the existing hydrological behaviors of the Mekong River flows for common understanding and agreement by riparian member countries. In the course of the study, technical definition of maintenance of flows, and preliminary flow regime analysis as well as drought analysis, were made based on the available hydrological data. Mainstream monitoring simulation by use of the past low flow regimes with the assumed minimum flow requirements was also made. The future framework of the Mekong River Hydro-Meteorological Monitoring System is further proposed for implementing the Rules.

RULES ON MAINTENANCE OF FLOWS ON THE MAINSTREAM

4. In the formulation of the Draft Rules for the Maintenance of Flows on the Mainstream, it is expected to provide the best judgment as to what "critical values" of the river must be protected. "Critical values" are those that the member riparian states agree should not be lost. These values are from an interpretation of what is "acceptable" with respect to Article 6, which requires the riparian states to maintain the minimum flows and forms the management principles of the Mekong mainstream.

5. Article 6 calls for the maintenance of "the acceptable minimum monthly natural flow during each month of the dry season on the mainstream" and states that wet season mainstream flows should also be sufficient to enable "the acceptable natural reverse flows of the Tonle Sap to take place." To provide the specific and social assessments of the impacts that change in flow regime might cause to the key attributes of the basin's resources, MRC has decided to follow an internationally accepted holistic approach (a holistic environmental flow methodology) to challenge for determining such acceptable flows that will maintain the acceptable level of health or conditions of the Mekong resources.

6. Article 6 complements Article 26 which calls for the five specific requirements to be considered for formulating the rules. They are: (i) establishing the time frame for the wet and dry seasons, (ii) establishing the location of hydrological stations, and determining and maintaining the flow level requirements at each station, (iii) setting out criteria for determining surplus quantities of water during the dry season on the mainstream, (iv) improving upon the mechanism to monitor intra-basin use, and (v) setting up a mechanism to monitor inter-basin diversions from the mainstream.

7. Along this line, the "Integrated Basin Flow Management (IBFM)-Mekong Method for Setting Flows for Sustainable Development" has just started in July 2003. This challenge will define what amount of flow change is socially, economically and ecologically acceptable. A key milestone of the MRC is to agree and implement the Rules for the Maintenance of Flows by the end of 2004. The IBFM Project will propose the agreed Interim Flow Plan (IFP) as the "initial" acceptable minimum monthly natural flow. The proposed IFP includes the projected flow regime changes resulting from the selected basin development scenario. As far as an individual development project would not modify flows beyond the agreed flow limits, the acceptable minimum monthly natural flows will remain unchanged.

8. Major specific requirements to be highlighted together with the current progress of rule making are as follows:

No.	Key Term	Progress/Undertaken
1	To establish the timeframe for the wet and dry seasons	Approved by the MRC Council in November 2003
2	To establish the location of hydrological stations, and to determine and maintain the flow level requirements at each station	Under the IBFM Project and Technical Drafting Group (TDG) 5
3	To set out the acceptable minimum monthly natural flow during each month of the dry season	Under the IBFM Project and TDG 5
4	To set out the acceptable natural reverse flow of the Tonle Sap to take place during the wet season	Under the IBFM Project and TDG 5
5	To set out criteria for determining surplus quantities of water during the dry season	Under the IBFM Project and TDG 5
6	To improve upon the mechanism to monitor intra-basin use	Approved by the MRC Council in November 2003
7	To set up a mechanism to monitor inter-basin diversions from the mainstream	Approved by the MRC Council in November 2003

LOW FLOW REGIME ON THE MEKONG MAINSTREAM

9. From March to April, the Mekong flows become the lowest. Specific discharges in March and April at hydrologic stations from Chiang Saen (189,000 km^2 in watershed area) to Kratie (646,000 km^2) on the Mekong mainstream vary within a smaller range of 3 to 5 liters/s/km^2, corresponding to 0.3 to 0.5 m^3/s per 100 km^2, or 30 to 50 m^3/s per 10,000 km^2.

From Kratie in Cambodia, an extensive floodplain area in the lower part of the Mekong is formed up to the Mekong Delta.

10. The Tonle Sap River joins the Mekong River at Phnom Penh in Cambodia. In the dry season the stored water in the Great Lake is gradually and naturally released into the Mekong mainstream through the Tonle Sap River. At the confluence of the Tonle Sap River, the Mekong River bifurcates into two rivers; the Mekong mainstream and the Bassac River. These two rivers enter the Mekong Delta in Vietnam. At present, water level and discharge are monitored at Tan Chau on the Mekong and at Chau Doc on the Bassac. These stations are located at about 10 km downstream from the Cambodia-Vietnam border and at about 200 km inland from the South China Sea.

11. Dry season flows into the Mekong Delta are partly dependent on the amount of wet season mainstream flows stored in the Great Lake. Specific discharges at the Mekong Delta inflow (combined flows at Tan Chau and Chau Doc, 756,000 km^2) in March and April are 5.4 and 4.2 liters/s/km^2, showing higher values than those at the upstream stations on the Mekong. Flow contributions from the Great Lake into the Delta are estimated to be 2.8 and 1.6 liter/s/km^2, respectively.

RECOMMENDATION ON NATURAL FLOW

12. In general, it might be difficult to obtain pure natural flow regimes since human activities are extensive. Hence the historic water use data are very necessary to estimate the natural flow on the basis of the measured flows. The actual current river flow regimes of the Mekong River are resulting from the accumulated effects of historic basin-wide water uses. However, from the practical points of view, the actual current flow regimes are recommendable as the natural flow regimes for the drafting process of the rules taking the following characteristics peculiar to the Mekong River Basin as well as facts into consideration.

13. The ongoing Basin Simulation Modeling Package and Knowledge Base would need to naturalize the measured hydrological flows. It is however reported that this Package has been confronted by difficulties and constraints of the serious lack of historic water usage data (mainly relating to irrigation developments) and sparse information available for effective model calibration.

14. The ongoing Basin Development Plan (BDP) would be formulated and implemented not to infringe on the existing water uses in the entire Lower Mekong Basin. It is very natural that the four member riparian states do not wish to lose or reduce any existing water uses. The highlighted acceptable limits of pattern of current flows would thus contain the existing water uses.

15. At the time of establishment of the Mekong Agreement in 1995, the technical term “natural” might merely mean the actual flow conditions before construction of a series of seasonal regulation large reservoirs on the Mekong mainstream. It was believed that the Mekong River was essentially unregulated and the existing low flow regimes are substantially close to the natural condition.

16. In Lao PDR, net increase of mainstream flow in the dry season is estimated to be around 90 m^3/s, subtracting the dry season irrigation demand of around 100 m^3/s (based on the assumption that approx. 100,000 ha of dry season irrigation with a diversion requirement of 1 liter/s/ha) from the average flow increase of 190 m^3/s due to the water release of Nam Ngum reservoir. In Thailand, the dry season flow was estimated to increase by around 45-60 m^3/s due to the supply balance of reservoirs. In Cambodia, low flow decreased by

around 68 m^3/s since the same assumption is applied to approx. 68,000 ha of dry season irrigation. The preliminary flow balance on the mainstream in the dry season implies that the existing off-stream use (irrigation use in majority) is negligibly small compared to the mean monthly flow of 2,800 m^3/s in April at the Cambodia-Vietnam national border into the Mekong Delta, when the Mekong flows become the lowest.

17. The Xiaowan Hydropower Project, a large-scale reservoir type project with active storage capacity of 11,500 million m^3, is under construction on the Mekong mainstream in China. This project will create the first seasonal flow regulation reservoir on the mainstream. This seasonal flow regulation will drastically change the Mekong flow regime especially significant increase of flows in the dry season (expectedly 550 m^3/s). The current flow regimes might be usable as the natural flow before completion of this project.

18. There might be no significant differences whether determination of the acceptable minimum level of flows is made on the basis of the current flow regimes or the estimated natural flow regimes. The acceptable minimum level of flows shall be practically applied to the current flow regimes. However, when some guidelines on water allocation (water sharing) among the states are established in future, evaluation of historic water usage and flow contribution by each state shall be on the basis of the estimated natural flows.

RECOMMENDATION OF QUANTIFICATION OF SURPLUS WATER

19. The four riparian states would not wish to lose or reduce any existing water use. The surplus quantity of water is theoretically obtained subtracting the agreed acceptable minimum monthly natural flow from the observed flow. The surplus quantity of water derived at some location means not the whole available water at this location but the total available water in the entire upper reaches. The estimated surplus water at this location already includes to some extent the surplus water at the upper reaches and is already allocated to some extent at the downstream reaches. If this concept is applied to the rules, the acceptable minimum monthly natural flows will increase whenever new water users are approved (new developments in tributaries can be made only by issuing the Notification). Thus the acceptable minimum monthly natural flows or the flow level requirements shall be modified and then the surplus water will decrease.

MEKONG DELTA AS A STARTING POINT FOR QUANTIFICATION OF SURPLUS WATER

20. Quantification of the surplus water in the entire Mekong River Basin shall be accounted for at the downstream end location of the Mekong River, preferably, at both the hydrologic stations of Tan Chau on the Mekong River and Chau Doc on the Bassac River where the total inflow into the Mekong Delta in Vietnam could be measured and monitored. The Mekong Delta is the starting point for analysis of the maintenance of flows on the Mekong mainstream.

21. Total inflow into the Mekong Delta in Vietnam is monitored at Tan Chau on the Mekong mainstream and at Chau Doc on the Bassac River. Magnitude of the dry season flows into the Mekong delta in relation to salinity intrusion length is the most important factor to the flow management. Tidal effects are very significant at both stations. The tidal range is greatest over the dry season period from March to May when flows are the lowest. Accurate and reliable monitoring of flows at both stations is difficult to make because of quick hourly changes of water level and velocity due to strong effects of tides. During the dry season, flow reversal occurs at both stations.

22. Observed hourly water level and discharge records at Tan Chau and Chau Doc are available for the period 1997-2001. The total mean annual inflow into the Mekong Delta (sum of discharges both at Tan Chau and Chau Doc) is 13,200 m^3/s. The total mean monthly inflow varies from 2,800 m^3/s in April to 26,300 m^3/s in September. Flow distribution between Tan Chau and Chau Doc is almost constant in the dry season. The Mekong River (at Tan Chau) delivers the flow volume of around 82% of the total inflow into Vietnam.

KEY ISSUES ON WATER RESOURCES MANAGEMENT IN THE MEKONG DELTA

23. Three key issues are highlighted from the aspect of current water use as well as water resources management in the Mekong Delta. They are: (i) water shortage in the dry season, (ii) seawater intrusion in the dry season, and (iii) acidification. Among them, issues (i) and (ii) are key factors in view of the determination of maintenance of flows on the Mekong mainstream. These issues are likely to intensify in the near future by impacts of various water resources development in upstream riparian countries.

24. Due to decrease of the Mekong flows in the dry season, seawater intrudes further upstream in the delta. The salinity intrusion into the delta is very complicated. The highest salinity is usually observed in April. Currently 1.7 million ha of the delta lands are affected by saltwater intrusion, which not only affects irrigation management but also domestic water supply. The problem is most severe in April when the Mekong flows become the lowest. It is said that 4 g/l saline level penetrates 30-40 km upstream.

25. Salinity intrusion impacts are different for each year, depending on not only hydrological conditions, but also on the irrigation water abstractions from the rivers that cause the decrease of flow to make deeper salinity intrusion. Thus increase of water use in the dry season leads to decrease the Mekong delta flows resulting in an increase of salinity intrusion. This would be a conflict between development and protection of water resources in the Mekong delta.

EXTREME DROUGHT IN 1998/99 AND IMPACTS OCCURRED

26. The year 1998 is the dry year resulting in the extreme drought that is readily understood by a wider range of local people engaging in agriculture and fishery activities. The maximum water level at Kratie, located on the Mekong mainstream, is considerably below the water levels in normal years. Water levels at both Tan Chau and Chau Doc showed the lowest variations, being around 1.5 m lower than in normal years. In the Mekong delta, impacts of the drought appeared in the coming dry season in 1999 as the considerably decreased inflows into the delta. The mean monthly inflows were 1,850 m^3/s in March and 2,200 m^3/s in April. They are the lowest compared to the mean monthly flows of 3,200 m^3/s in March and 2,800 m^3/s in April.

27. Significant issues arose from the environmental impacts of the flow regime changes in the dry year 1998. Drastic decrease of maximum water level occurred in the Great Lake. The estimated maximum water level and volume of the Lake are around 6 m and 28 billion m^3 in 1998 and 9.5 m and 65 billion m^3 in 2000 in normal years. The lake inundation areas are significantly different from around 13,000 km^2 in 1998 to 5,500 km^2 in 2000. The floodplains in Cambodia are very productive for young fishes for growing and migration and thus fish productivity has a close relation with the extent and duration of floodplain inundation. Due to drastic reduction of inundation area in, drastic decrease of fish catch in 1998/99 in Cambodia has occurred from the environmental consequences. Since inland

fishery is of great economic and social importance in Cambodia, associated socio-economic impacts were very significant.

28. The decreased dry season flows in the Mekong delta in 1999 allowed salty seawater to intrude further upstream than in normal years. Salinity concentrations drastically increased. At Tra Vinh on the Mekong, the maximum salinity was recorded at more than 10 g/l, where usually less than 6 g/l. At Dai Ngai on the Bassac, the salinity increase was more significant as it increased to around 10 g/l from less than 4 g/l in most years. No information is however available on the impacts to agricultural activities in the delta.

29. The floodplain inundation in terms of fisheries activities and fish dynamics, and salinity intrusion in terms of agricultural activities in the delta are key attributes for determination of the environmental flows under the IBFM project.

DROUGHT ANALYSIS ON THE MEKONG MAINSTREAM

30. Actual hydrological events are changeable and their behaviours largely fluctuate. The occurrence of events is probabilistic and stochastic. Thus hydrological events (flow regime) may vary from season to season, from year to year and from place to place. This is easily undestandable in terms of difference of occurrence probabilities of a hydrological event. There are great varieties of dry year events such as a basin-wide dry year in 1992 and partially basin-wide dry year in 1998.

31. Probability of occurrence of the dry year in 1998 was evaluated at nine stations from Chiang Saen to Pakse on the Mekong mainstream by means of the total seasonal flow volume in the wet season (from June to November). Estimated probabilities are different from station to station varying from 0.5 (to be occurred once in 2 years) at Chiang Saen to 0.025 (once in 40 years) at Pakse. Considering lower probabilities from Mukdahan to Pakse, it implies that severe drought occurred in wider range of the contributing left bank tributaries in Lao PDR and Vietnam; Se Bang Hien, Se Sang, Se Kong and Sre Pok Rivers. These tributaries contribute around 22% of the annual runoff of the Lower Mekong Basin, although area contribution is only 13%. It could be argued that these tributaries are the dominant influence on the incidence and severity of drought in the Mekong delta.

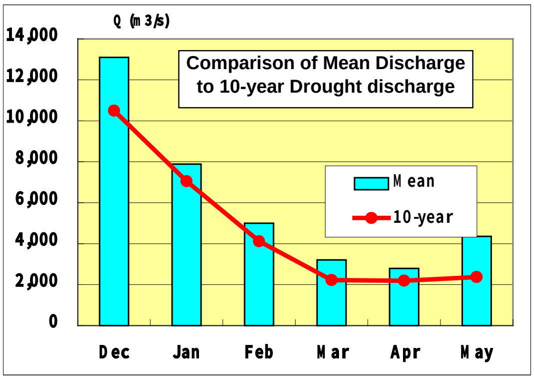
FLOW REGIME ANALYSIS ON THE MEKONG MAINSTREAM

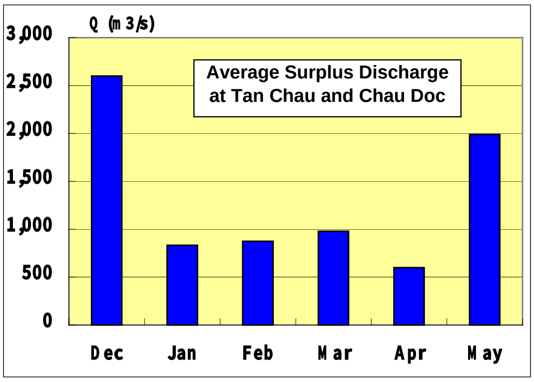
32. Monthly mean discharges of several non-exceedance probabilities were estimated for the ten stations on the Mekong mainstream from Chiang Saen to Pakse based on the monthly mean discharge data. The estimated drought discharges compared to the monthly mean discharges in dry years in 1992 and 1998 are as follows:

Station	Drainage Area (km2)	Mar					Apr				
		Mean	10-year	5-year	1992/93	1998/99	Mean	10-year	5-year	1992/93	1998/99
Chiang Saen	189,000	835	660	730	801	702	915	700	820	824	645
Lua. Prabang	268,000	1,065	890	920	1,025	673	1,112	900	990	1,011	625
Chiang Khan	292,000	1,043	870	910	962	969	1,056	890	920	881	943
Vientiane	299,000	1,167	960	1030	1,046	755	1,194	970	1030	974	766
Nong Khai	302,000	1,176	1,020	1,090	1,214	971	1,215	1,030	1,100	1,110	991
Na. Phanom	373,000	1,548	1,230	1,310	1,224	1,454	1,526	1,160	1,230	1,108	1,692
Mukdahan	391,000	1,600	1,300	1,450	1,548	1,343	1,569	1,290	1,430	1,453	1,514
Khon Chiam	419,000	1,903	1,520	1,640	1,845	1,616	1,839	1,520	1,610	1,775	1,789
Pakse	545,000	1,852	1,490	1,650	1,575	1,502	1,819	1,520	1,600	1,449	1,778
Delta Inflow	756,000	4,120	2,230	3,450	4,024	1,852	3,204	2,200	2,440	2,856	2,191

PRELIMINARY QUANTIFICATION OF SURPLUS WATER ON MEKONG MAINSTREAM

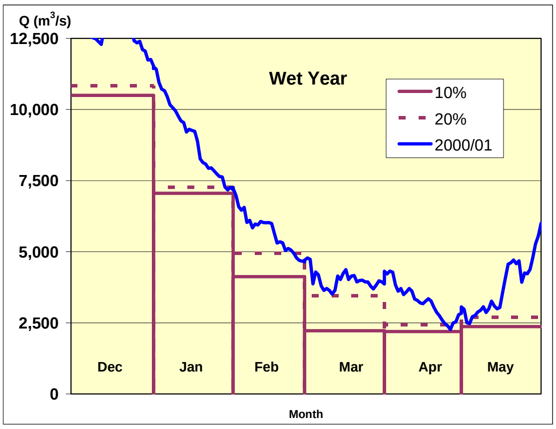
33. Preliminary quantification of the surplus water is made at the national border entering the Mekong Delta (combination of Tan Chau and Chau Doc) by use of the 10-year drought discharges, which are assumed to be the acceptable minimum monthly natural flows. The applied monthly discharges at both stations are the observed ones in 1997-2001. It is noted that the surplus quantity of water is still variable and stochastic. Hence, the flow regime may vary from season to season, from year to year and from station to station.

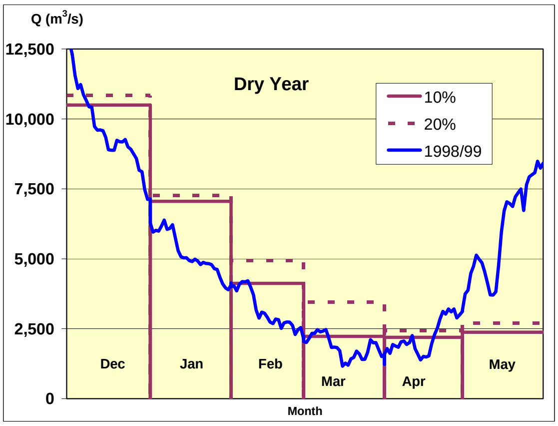




MONITORING SIMULATION OF MAINSTREAM FLOWS

34. Maintaining dry season flows on the Mekong mainstream is one of the most important management activities confronting the MRC. Mainstream monitoring simulation was made by use of the past representative flow regimes with the assumed minimum flow requirements; monthly 10-year (10% of non-exceedance probability) and 5-year (20%) drought discharges at respective hydrological stations from Chiang Saen to Tan Chau and Chau Doc on the Mekong Delta. Example of monitoring at the entry point into the Mekong Delta is shown below.





35. The end and onset of the wet season are changeable. Thus the actual flows are likely to intersect the 10-year monthly drought discharges at several stations where they are assumed as the acceptable minimum monthly natural flows during each month of the dry season. Nevertheless, no action necessary for the maintenance as stipulated in Article 6 might be necessary, as major portions of flows in such transition period flows into the sea without any use. To avoid such inconveniences, the acceptable flows shall be carefully and practically set out, preferably be smaller flows than 10-year drought discharges.

SUPPLEMENTARY GUIDELINE OF DROUGHT MANAGEMENT

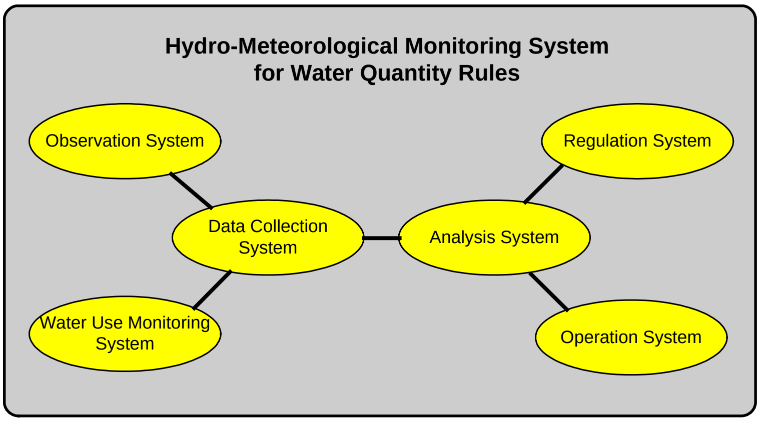
36. The purpose of Article 6 is the recognition by all the riparian states of the need to cooperate in maintaining mainstream flow levels within the determined acceptable flow levels. However, it is clearly acknowledged that Article 6 does not impose any duty upon the member states for the observance of the rules during emergency situations of exceptionally extreme drought. Due to the great variation of hydrological events, it is likely that the existing flows are beyond the acceptable flow limits at some stations, but are within the limits at other stations. In this situation, Article 6 calls for undertaking of some actions necessary for the maintenance on the mainstream flow levels. Conceivable actions to be taken as a drought management in general are restriction of the existing water uses and/or emergency water supply from the existing reservoirs. These actions presumably seem to be unpractical at the moment considering implementation of such actions requires in principle recognition and compromise by all the member states with regards to whether monetary compensation issues for emergency release of the water as well as curtailment of existing water uses are agreeable or not. Nevertheless possibility and necessity of drought management are subject to discussion under the IBFM project.

MEKONG RIVER HYDRO-METEOROLOGICAL MONITORING SYSTEM FOR WATER QUANTITY RULES

37. Overall, it is expected that development pressure on the Mekong mainstream is likely to be relatively low, but medium to large-scale development pressure will become higher on some tributaries. All four countries agreed on the general principle that water of the Mekong River is a shared resource, whereas states have a higher priority on the use of tributary waters within their countries. It is considered that the Agreement allows flexibility for each country to undertake development activities in tributaries. In the future as a consequence of excessive water use and abstraction in tributaries in the dry season, these activities will sooner or later create issues that low flows on the mainstream will decrease beyond the flow limits and especially in case of severe drought serious water shortage and conflicts might arise.

38. According to Articles 5, any future water uses on the mainstream will be proposed within the acceptable flow limits throughout the dry season. However, new water users in tributaries can basically develop with only issuing the Notification to the Joint Committee both in the wet and dry seasons. It is superficially interpreted that the current and future water uses can be independently managed by the existing water right system of each riparian country.

39. In this sense, the establishment of Mekong River Hydro-Meteorological Monitoring System for Water Quantity Rules will be urged to ensure effective implementation of the water utilization rules as proposed for river flow monitoring in Article 26. The System comprises six components.



40. The System will be preferably in the long future integrated into the Mekong River Integrated Basin Flow Management System together with the existing Flood Forecasting System that is to be strengthened under the Flood Management and Mitigation Program, and the future Water Quality Monitoring System for Water Quality Rules. Twenty-seven stations are recommended for implementation of the Water Quantity Rules, and the stations for setting up the Interim Flow Plan (IFP) for maintaining the mainstream flow requirements are recommended, although they are subject to discussion and final selection under the ongoing IBFM Project.

Proposed Monitoring Stations of the Mekong River Hydro-Meteorological Monitoring System

No.	Station (Country)	River	Drainage Area (km^2)	Classi-fication	Setting of IFP	Remarks
1	Man'an (China)	Mekong (Lancang)	114,500	-	X	Monitoring of outflow from the Manwan dam
2	Yunjinghong (China)	Mekong (Lancang)	160,000?	-	X	Trans-boundary station. Monitoring of inflow into the LMB
3	Chiang Saen (Thailand)	Mekong	189,000	Key	O	Trans-boundary station. Monitoring of inflow into the LMB and navigation management
4	Luang Prabang (Lao PDR)	Mekong	268,000	Key	O	Trans-boundary station. Monitoring of inflow into Lao PDR territory
5	Chiang Khan (Thiland)	Mekong	292,000	Key	O	Monitoring of Mekong flow at the border between Thailand and Lao PDR territories
6	Vientiane (Lao PDR)	Mekong	299,000	Primary	O	Monitoring of Mekong flow at the border between Thailand and Lao PDR territories
7	Nong Khai (Thailand)	Mekong	302,000	Key	O	Monitoring of Mekong flow at the border between Thailand and Lao PDR territories
8	Pak Kagnung (Lao PDR)	Nam Ngum	14,300	Key	X	Monitoring of Nam Ngum inflow into the Mekong including the Nam Ngum dam
9	Nakhon Phanom (Thailand)	Mekong	373,000	Key	O	Monitoring of Mekong flow at the border between Thailand and Lao PDR territories
10	Mukdahan (Thailand)	Mekong	391,000	Key	O	Monitoring of Mekong flow at the border between Thailand and Lao PDR territories
11	Ban Keng Done (Lao PDR)	Se Bang Hiang	19,400	Key	X	Monitoring of Se Bang Hiang inflow into the Mekong
12	Khong Chiam (Thailand)	Mekong	419,000	Key	O	Monitoring of Mekong flow at the border between Thailand and Lao PDR territories
13	Ubon (Thailand)	Nam Mun-Chi	104,000	Key	X	Trans-boundary station. Monitoring of Nam Mun-Chi inflow into the Mekong including many large dams
14	Pakse (Lao PDR)	Mekong	545,000	Key	O	Trans-boundary station. Monitoring of outflow to Cambodia territory
15	Ban Komphoun (Cambodia)	Se San	48,200	Key	X	Monitoring of Se San Inflow into the Mekong
16	Ban Khmoun (Cambodia)	Se Kong	29,600	Primary	X	Monitoring of Se Kong Inflow into the Mekong
17	Stung Treng (Cambodia)	Mekong	635,000	Key	O	Trans-boundary station. Monitoring of inflow into Cambodia territory
18	Kratie (Cambodia)	Mekong	646,000	Key	O	Monitoring of Mekong flow. Key representative station for the Acceptable Natural Reverse Flow of the Tonle Sap during the wet season
19	Kompong Cham (Cambodia)	Mekong	660,000	Key	O	Monitoring of Mekong flow and mainstream inflow to the Chak Tomuk junction at Phon Penh
20	Kompong Luong (Cambodia)	Great Lake	43,800	Key	X	Monitoring of water level at the Great Lake
21	Prek Kdam (Cambodia)	Tonle Sap	84,400	Key	O	Monitoring of inflow & outflow of the Great Lake
22	Phnom Penh Port (Cambodia)	Tonle Sap	?	Primary	X	Monitoring of inflow & outflow of the Great Lake. Monitoring of flow distribution at Phnom Penh (Chak Tomuk junction)
23	Chroui Changvar (Cambodia)	Mekong	663,000	Primary	X	Monitoring of flow distribution at Phnom Penh (Chak Tomuk junction)
24	Neak Luong (Cambodia)	Mekong	?	Key	X	Trans-boundary station. Monitoring of inflow into the Mekong Delta
25	Tan Chau (Vietnam)	Mekong	?	Key	O	Trans-boundary station. Monitoring of inflow into the Mekong Delta
26	Chak Tomuk (Cambodia)	Bassac	?	Key	X	Monitoring of flow distribution at Phnom Penh (Chak Tomuk junction)
27	Chau Doc (Vietnam)	Bassac	?	Key	O	Trans-boundary station. Monitoring of inflow into the Mekong Delta

41. It is expected that modernization will provide for automatic data collection and real-time transmission of data to MRC and riparian countries. Telemetry network stations under establishment of the ongoing AHNIP (totally 17 hydrological mainstream stations including 2 stations in China) are fully utilized for the proposed observation network. Data will be required for both the mainstream and tributaries that would cause impacts to mainstream flow regimes.

42. Data on the past or current water uses are so far not readily available. There does not exist a shared understanding among the member states of their respective use of water. Discussion of the “reasonable and equitable use” of the Mekong waters would not be possible unless water uses are identified and quantified. Moreover, it may be necessary to monitor water use to ensure that water use estimates are accurate and to provide a means of water use control

during periods of droughts and extremely low flows. Monitoring the release of water from reservoirs might also be important during severe droughts. The Procedures for Water Use Monitoring, approved by the Joint Committee in November 2003, stipulates to establish a Water Use Monitoring System by MRC and member countries to monitor water use in the Mekong River Basin. Although the details of the System component are subject to determination by a technical support team within MRC, the existing large seasonal regulation reservoirs shall be monitored with focus on the release of water and reservoir water level as well as the remaining water volume in thereservoir.

SUPPLEMENTARY GUIDELINE OF WATER SHARING

43. Once the surplus quantity of water is determined, the allocation of surplus water (water sharing) between the member states might need to be agreed upon. Although the Agreement stipulates the necessity of utilization of Mekong waters in a reasonable and equitable manner, it does not provide any water allocation, or more specific water allocation arrangements. Under the recently agreed rules "Procedures for Notification, Prior Consultation and Agreement," once individual development proposals in any tributaries are agreed upon, each country could undertake development and use water with the opportunity to exercise sovereign powers and independence. Nevertheless without agreed water sharing, this application might not substantially allow the countries with little developments to be given equal development opportunity with countries that already have significant developments. One of the concepts is that trading or swapping between riparian countries in rights to change the agreed upon water sharing might be allowed.

44. In this respect, some guidelines to solve such water allocation issues among the member states might be necessary in the immediate future. Clarification and evaluation of historic water usages and/or flow contributions (such as low flow increase by water release from reservoir) by each riparian country would be the starting point for water allocation that shall be the basis for determination of a basin development scenario under the IBFM project. This technical guideline or standard shall be formulated through a number of discussions among the member states in view of the sustainable cooperative uses of the Mekong waters preferably before completion of the ongoing Xiaowan Dam in China, since this dam is expected to cause drastic low flow increase by 550 m^3/s on the mainstream.

1. INTRODUCTION

1.1 The 1995 Mekong Agreement

On 5 April 1995, the governments of the four riparian countries in the Lower Mekong River Basin; namely, Cambodia, Lao PDR, Thailand and Vietnam, signed a historic "Agreement on the Cooperation for the Sustainable Development of the Mekong River Basin". The 1995 Mekong Agreement consists of six chapters with 42 articles. It set a new mandate for the organization "to cooperate in all fields of sustainable development, utilization, management and conservation of the water and related resources of the Mekong River Basin" and newly established the Mekong River Commission (MRC). The Agreement brought a change of identity for the organization previously known as the Mekong Committee, which had been established in 1957 as the Committee for Coordination of Investigation of the Lower Mekong Basin.

The MRC is an intergovernmental body and has launched a process to ensure "reasonable and equitable use" of the Mekong River System, through a participatory process with the National Mekong Committee in each country to develop rules and procedures for water utilization. The MRC monitors the quality of water resources, and is supporting a joint basin-wide planning process with four countries called the Basin Development Plan. The MRC is also involved in fisheries management, promotion of safe navigation, agricultural development, flood mitigation and hydropower planning within an overall framework of renewable resources management. The two upper states of the Mekong River Basin, the People's Republic of China and the Union of Myanmar, are dialog partners to the MRC.

1.2 Structure of MRC

According to Article 12 of the Agreement, the MRC consists of three permanent bodies; the Council, the Joint Committee (JC) and the Secretariat from the hierarchical order. The Council, comprising one member at Ministerial and Cabinet level from each MRC member country, convenes annually and has overall governance of the MRC.

The JC, also comprising one member from each member country at Head of Department level or higher, convenes at least two times a year. This body functions as a board of management. The Secretariat provides technical and administrative services to the JC and the Council under the supervision of the JC. A Chief Executive Officer (CEO) appointed by the Council shall be the director of the Secretariat. The National Mekong Committee (NMC) in each state shall coordinate MRC programmes at the national level and provide links between the MRC Secretariat and the national ministries and line agencies. The principal implementing agencies of the MRC programmes and projects are the line agencies of the riparian countries in the Lower Mekong Basin.

1.3 Programme Approach of MRC

Approved by the Council in October 2000, a new approach launched with the main focus of activities on nine programs under three categories; the Core Programmes, Sector Programmes and Support Programme, as follows:

Table 1.1 Programme Approach of MRC

Category	Programme
Core Programmes	1. Basin Development Plan (BDP)
	2. Water Utilization Programme (WUP)
	3. Environment Programme (EP)
Support Programme	4. Capacity Building Programme
Sector Programmes	5. Fisheries Programme
	6. Agriculture, Irrigation and Forestry Programme
	7. Navigation Programme
	8. Water Resources and Hydrology Programme
	9. Tourism Programme

Source: Mekong River Commission, Annual Report 2000

The three Core Programmes are being implemented collaboratively with each other aiming at addressing key issues in the 1995 Mekong Agreement. The activities under the core programmes are in the long term. Their major activities and relations are presented in Fig. 1.1. Besides the above, the new Flood Management and Mitigation Programme were approved by the Council in November 2002. Together with these programmes above, sub-programmes are ongoing with assistance from many donor countries. They collaborate within the framework of WUP as shown in Fig. 1.

1.4 Water Utilization Programme (WUP)

The Water Utilization Programme (WUP) is being undertaken to help the member states of the MRC to implement key elements of the 1995 Mekong Agreement on the cooperation for the sustainable development of the Mekong basin. The broad objectives are to:

(1) Assist the MRC put in place a mechanism to promote and improve coordinated and sustainable water management in the basin and among the riparian countries,

(2) Promote reasonable and equitable water utilization by the countries, and

(3) Enhance the protection of the environment, aquatic life and ecological balance of the basin.

This would be achieved through preparation of appropriate "Water Utilization Rules" for water quantity and quality, and for information exchange, notification, consultation and agreement, in accordance with the principles and articles in the Agreement. The WUP is an extensive programme with many inter-linked components. The programme will provide the tools and related knowledge base to enable MRC and its member countries to gain a deeper understanding of hydrological linkages between the natural environment, water use and trans-boundary impacts on water, society and the environment. At its 6th meeting in October 1999, the MRC Council fully endorsed the WUP, and committed their governments to "undertaking good faith efforts" to negotiate and complete specific sets of rules for water use. As the result, the WUP started in early 2000 as a 6-year programme funded by the Global Environment Facility (GEF) through the World Bank. Execution of the WUP activities is being carried out through 3 working groups (WG1 to WG3) supervised by members of the MRCS WUP Unit under the CEO; namely,

WG1: Basin Modeling and Knowledge Base

WG2: Environmental and Trans-boundary Analysis

WG3: Rule Formulation

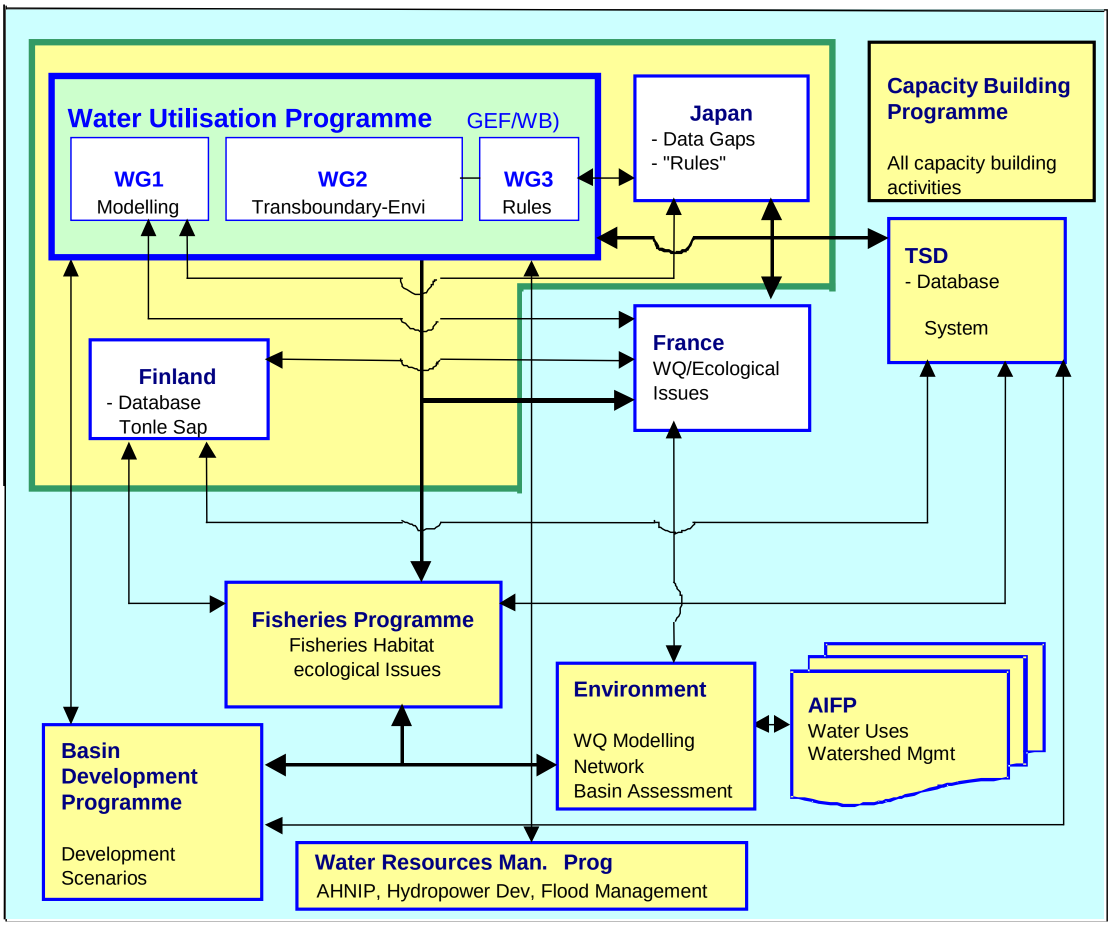


Fig. 1.2 Framework of Ongoing MRC Programmes and Sub-Programmes

WG1: Basin Modeling and Knowledge Base (WUP-A):

The main responsibilities of WG1 are the coordination and supervision of activities related to the development of analytical tools comprising a basin modeling and knowledge base intended to support decision making for basin planning and management through assessment of the physical, environmental and socio-economic impacts of development options. The progress in development of the basin modeling and knowledge base, collectively known as the Decision Support System (DSF), is to be completed and handed over to the MRC until the end of 2003. As for the co-financed sub program from the Government of Finland (so-called WUP-FIN Project), with the project name of Modeling of the Flow Regime and Water Quality of the Tonle Sap, it aims at providing an enhanced knowledge base, analytical tools (3-dimensional EIA Flow Model for computation of water currents, water levels and flooding for the lake and floodplains, and 3-dimentional EIA Water Quality Model for computation of transport and processes of a selected set of water quality indicators and hazardous materials) and guidelines to improve understanding of the interaction of the physical and biological feature of the Tonle Sap Lake.

WG2: Environmental and Trans-boundary Analysis:

WG2 has been continuing the awareness-raising of the riparian countries in trans-boundary impact assessment resulting in identifying agreed issues of high trans-boundary significance, namely, declining fish production, flooding, dams on the mainstream, sedimentation, reduced dry season flows, and water quality deterioration. The other main area of WG2 has been in introduction of flow management concepts resulting in the development of a flow management proposal for a three-phase "environmental flow" approach for managing the health of the Mekong River jointly with the EP within MRC as a part of the WUP-Project Implementation Plan project.

WG3: Rule Formulation:

Rule-making process has been undertaken through the WUP. Water Utilization Rules to be formulated comprise four Procedural Rules and two Technical Rules as listed below.

Table 1.2 Water Utilization Rules to be Formulated under WUP

Category	Rule
Procedural Rules	1. Procedures for Data and Information Exchange and Sharing (approved in July 2001)
	2. Preliminary Procedures for Notification, Prior Consultation and Agreement (approved in November 2002 with pending issues)
	3. Procedures for Water Use Monitoring (approved in November 2003)
	4. Procedures for Notification, Prior Consultation and Agreement (approved in November 2003)
Technical Rules	5. Rules for the Maintenance of Flows (to be approved by the end of 2004)
	6. Rules for Water Quality (to be approved by the end of 2005)

Source: Mekong River Commission, Annual Report 2001

Under the WG3, five Technical Drafting Groups (TDG) were established for development of each rule above. TDG undertakes to draft the rules format (legal text) before entering into negotiation and agreement by the Joint Committee. TGD were respectively established for each rule formation.

The Procedures for Data Exchange and Sharing provides for a broad range of data and information to be exchanged among the member countries. Data and information on water resources, topography, natural resources, agriculture, navigation and transport, flood management and mitigation, infrastructure, urbanization, industrialization, environment and ecology, administrative boundaries, socio-economic changes, and tourism, all fall within the scope of this agreement. Each of these areas will later be defined in more detail.

The Preliminary Procedures for Notification, Prior Consultation and Agreement prescribes a format for various obligations of the member countries on future water uses distinguishing between uses on the mainstream and the tributaries, and between uses during the wet and dry seasons. However the Procedures are preliminary so that they will be refined before finalization in 2003 based on the experiences gained through their application.

The Procedure for Water Use Monitoring are being drafted as a framework with reference to the technical subcommittee of TDG3 to enable flexible specifications on a continuing basis of the technical issues related to the procedures. The Water Use Monitoring is a procedural rule, which stipulates to establish a water use monitoring system by MRC and member countries to monitor water use in the Mekong River basin and inter-basin diversion.

1.5 Rules for the Maintenance of Flows

Development of rules must address the specific requirements of the Agreement. Although to be discussed in detail in Chapter 2, Article 6 calls for the maintenance of "the acceptable minimum monthly natural flow during each month of the dry season on the mainstream" and states that wet season mainstream flows should also be sufficient to enable "the acceptable natural reverse flows of the Tonle Sap to take place." To provide the specific and social assessments of the impacts that change in flow regime might cause to the key attributes of the basin's resources, MRC has decided to follow an internationally accepted holistic approach (a holistic environmental flow methodology) to challenge for determining such acceptable flows that will on the other hand maintain the acceptable level of health or conditions of the Mekong resources. Along this line, the "Integrated Basin Flow Management (IBFM)-Mekong Method for Setting Flows for Sustainable Development" has just started in July 2003. This challenge will identify the relationship between various flow regimes/scenarios (range of levels of basin development) and key social, economical and ecological components identified by the four NMCs. This information when linked witth the basin modeling being carried out by the WUP-A will result in the identification, description and prioritization of a number of scenarios for the management of river flows, each having social, economical and ecological implications. A key milestone of the MRC is to agree and implement the Rules by the end of 2004. The rule-making process will be undertaken by TDG5.

1.6 Purpose of This Study

One of the main objectives of the WUP-JICA study is to provide MRC with technical assistance in drafting process of the preparation of the Draft Rules for Water Utilization under the WUP activities. Among the Rules, the technical assistance especially for the Rules for the Maintenance of Flows on the Mainstream (Rules for Water Quantity) stipulated in Article 6 of the Agreement is expected WUP-JICA by MRC.

The purpose of this work is to provide technical and hydrological supplementary information for supporting framework procedures of the rule preparation with the main focus of the existing hydrological behaviors of the Mekong River flows for common understanding and agreement by riparian member countries. In the course of the study, technical definitions of maintenance of flows, and preliminary flow regime analysis as well as drought analysis were made based on the available hydrological data. Mainstream monitoring simulation by use of the past low flow regimes with the assumed minimum flow requirements was also made. Furthermore, the future framework of the Mekong River Hydro- Meteorological Monitoring System is proposed containing a proposal of the monitoring stations for implementing the Rules. This paper presents all the results of basic study on the maintenance of flows on the Mekong mainstream. This study is a continuation of the study that was carried out in the second phase of WUP-JICA Study in years of both 2002 and 2003.

The study also aims at providing technical information and drawing attention on some pertinent issues related to a rule-making process by the TDG5 as well as a future hydrological monitoring on the Mekong mainstream in accordance with the Rules for the Maintenance of Flows on the Mainstream. Moreover, this paper also aimed at materialization for two workshops: (i) Regional Training Workshop on Water Allocation and Monitoring: International Experiences that was successfully carried out on 23-25 January 2002 at Ho Chi Minh City in Vietnam, and (ii) Regional Training Workshop on Integrated Water Management in the LMB on 15-16 December 2003 at Phnom Penh in Cambodia.

2. PRELIMINARY DEFINITION OF MAINTENANCE OF FLOWS FROM TECHNICAL VIEWPOINTS

2.1 Rules for Water Utilization and Inter-Basin Diversions

The 1995 Mekong Agreement stipulates in Article 26 the rules for water utilization and inter-basin diversions as displayed below.

Article 26: Rules for Water Utilization and Inter-Basin Diversions

The Joint Committee shall prepare and process for approval of the Council, inter alia, Rules for Water Utilization and Inter-Basin Diversions pursuant to Articles 5 and 6, including but not limited to:

1) Establishing the time frame for the wet and dry seasons;

2) Establishing the location of hydrological stations, and determining and maintaining the flow level requirements at each station;

3) Setting out criteria for determining surplus quantities of water during the dry season on the mainstream;

4) Improving upon the mechanism to monitor intra-basin use; and

5) Setting up a mechanism to monitor inter-basin diversions from the mainstream

As shown above, Article 26 requires five specific requirements to be considered for formulating the rule. Illustration below shows the relationship of the required process in Article 26 with a specific focus on the determination of surplus quantities of water on the Mekong mainstream.

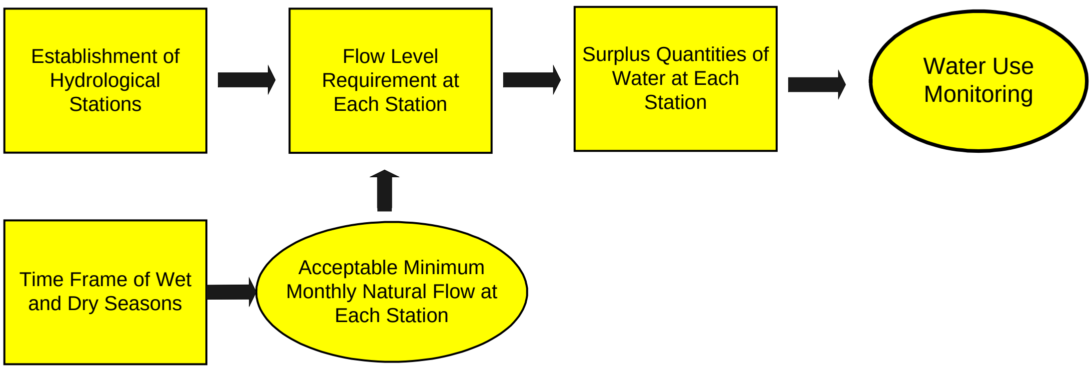


Fig. 2.1 Simplified Procedure of Required Activities in Article 26

As seen above, water use monitoring might be implicitly required at the hydrological locations based on the requirement of 2) in the Article 26 above after the rule formulation.

In relation to the Rules for Water Utilization, other several articles in the Agreement complement Article 26. Key features of related articles of particular interest are illustrated as follows.

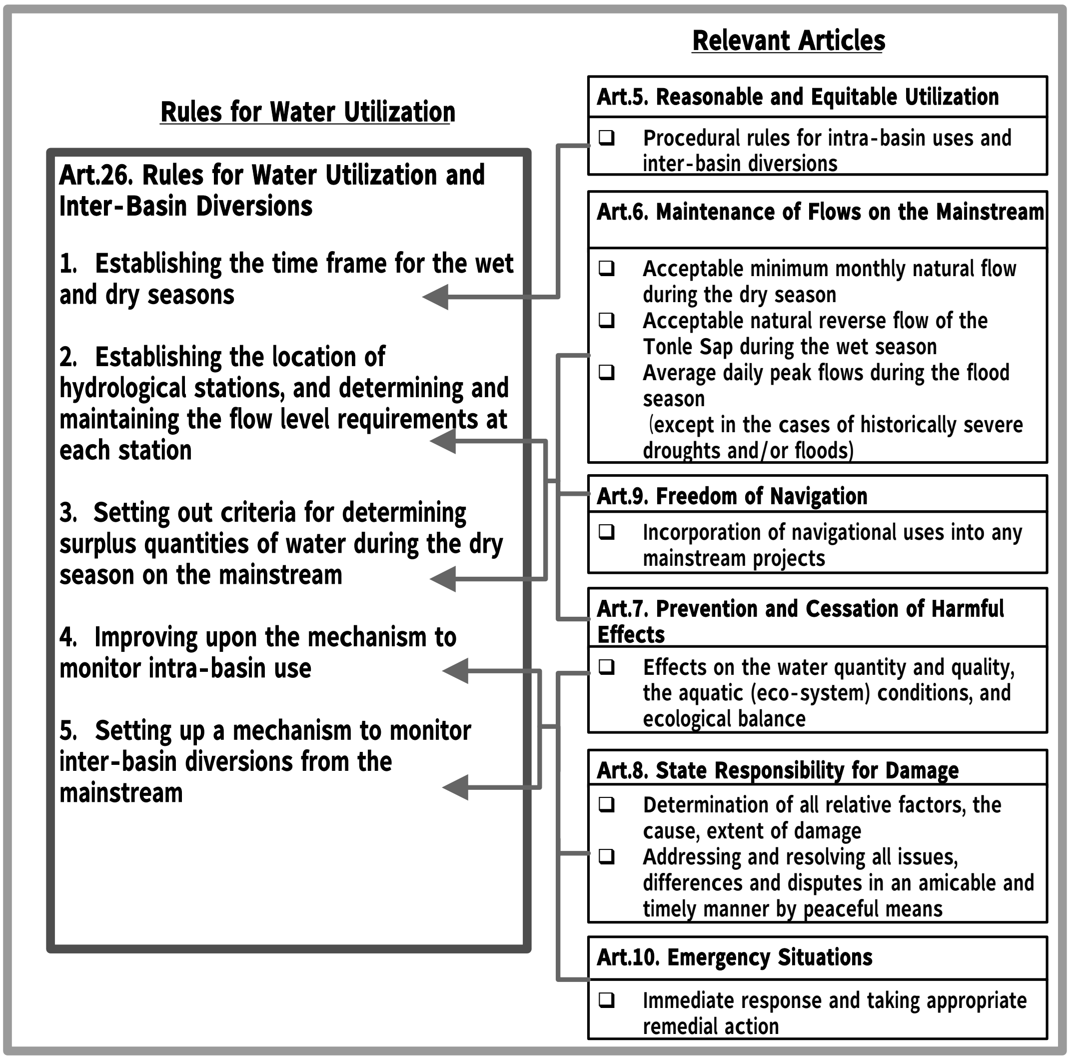


Fig. 2.2 Water Utilization Rules and Relevant Articles of Particular Interest

2.2 Maintenance of Flows on the Mekong Mainstream

In preparing the Rules for Water Utilization and Inter-Basin Diversions, Article 6 addresses three maintenance flow requirements on the Mekong mainstream. Article 6 requires the riparian countries to maintain and monitor the minimum flows on the Mekong River. Article 6 might help to satisfy the fundamental water resources interests of the negotiators from riparian countries at preparation of the Mekong Agreement in 1995. These flows are most specific requirements for interpretation and then definition as the rule, which might form the management principles or goals of the Mekong mainstream and the logical starting point for the rule formulation. Displayed in the box below is the provision of Article 6.

Article 6: Maintenance of Flows on the Mainstream

To cooperate in the maintenance of flows on the mainstream from diversions, storage releases, or other actions of a permanent nature; except in cases of historically severe droughts and/or floods:

A. Of not less than the acceptable minimum monthly natural flow during each month of the dry season;

B. To enable the acceptable natural reverse flow of the Tonle Sap to take place during the wet season; and

C. To prevent average daily peak flows greater than what naturally occur on the average during the flood season.

The Joint Committee shall adopt guidelines for the locations and levels of the flows, and monitor and take action necessary for their maintenance as provided in Article 26.

In summary Article 26 is complemented by Article 6 and Article 6 calls for three kinds of maintenance of flows on the mainstream with respect to (i) natural dry season flows, (ii) wet season flows sufficient to enable the acceptable natural reverse flow of the Tonle Sap River, and (iii) peak flood flows. However, the acceptable minimum monthly natural flow will not be secured fully in the cases of historically severe drought.

In case these terms are put into practice, the following various arising questions are of some noteworthy aspects for technical definition (presumably have been discussed so far for a long time, but not yet concluded with mutual consensus among riparian countries):

- What the term **"acceptable"** could mean? What is the definition of "the acceptable minimum"? What is "the minimum level of flows" and how to determine it?

- What constitutes **"the acceptable flows"**? What are basic elements for defining "the acceptable flow"? Shall "the acceptable minimum flow" be defined in terms of flow magnitude and flow pattern? How much change of the flow regime is acceptable?

- What the term **"natural"** mean? What is the difference between "the natural flow" and the current flow? How to determine "the natural flow"? Does "the natural flow" include the existing water uses (water extractions)? Shall "the acceptable flow" be established based on the natural flow regime?

- The acceptable minimum monthly natural flow includes **"the existing water use"** and/or **"future water use** (allocated river water to each riparian country for future uses)"? (There is some opinion that at the time of establishment of the 1995 Mekong Agreement the natural flow simply meant the observed flows before regulation of the planned large-scale dams on the Mekong mainstream).

- An **"environmental flow"** (which is the river flow of widespread concern and to be discussed in succeeding sub-sections) ideally equals to the acceptable minimum monthly natural flow?

- The acceptable minimum monthly natural flow equals to or contains the essentially required flow for "the ecological health of the Mekong River"?

- What are the essential parameters (key attributes) for determining **"the acceptable minimum monthly natural flow"**?

- In Chapter II: Definitions of Terms of the Mekong Agreement, **"the acceptable natural reverse flow of the Tonle Sap"** is determined as "the wet season flow level in the Mekong River at Kratie that allows the reverse flow of the Tonle Sap to an agreed upon optimum level of the Great Lake". What does the term **"an agreed upon optimum level of the Great Lake"** mean? How is it evaluated and determined? Shall "the acceptable natural reverse flow at Kratie" be determined as flow patterns (regime) on a daily or monthly basis? Shall this term only be applicable to some future development planning of seasonal regulation large reservoirs?

- How do we evaluate the mainstream flood flows in terms of magnitude and define the "average daily peak flows greater than what naturally occur on the average" during the flood season? What does the term **"naturally occur on the average"** mean?

- How do we evaluate and define the **"historically severe droughts and floods"**?

As indicated above the wording of Article 6 seems technically ambiguous. In summary, in order to develop into rules, the terms in Article 6 would need to be interpreted in terms of unambiguous quantification of required flows through the following:

(1) Clarification of the terms "acceptable" and "natural" both for minimum monthly dry season flows and for reverse flow of Tonle Sap in the wet season that is to be indicated by the wet season flow level at Kratie on the Mekong mainstream.

(2) Clarification of the term "an agreed upon optimum level of the great Lake" in relation to definition of the reverse flow of Tonle Sap in the wet season.

(3) Clarification of the term "average daily peak flows greater than what naturally occur on the average" during the flood season.

(4) Establishment of the extent of allowable exceptional cases for the required flows above through assessment of historically severe droughts and floods.

(5) Quantification of required flows at specific locations and times.

2.3 In-stream, On-stream and Off-stream Water Uses

One of the highlights in the Mekong Agreement is the provision of the principle of reasonable and equitable use of the Mekong water resources as stipulated in Article 5. The water utilization shall be pursuant to all relevant factors and circumstances although they are not specified in the Agreement. Article 5 specifies obligations of member countries on water use dividing them into three categories: (i) source of water whether on the Mekong mainstream or on the tributaries, (ii) season whether during the wet season or dry season, and (iii) location of use whether the intra-basin (within the Mekong Basin) or inter-basin diversion outside of the Mekong Basin.

Article 5: Reasonable and Equitable Utilization

To utilize the waters of the Mekong River system in a reasonable and equitable manner in their respective territories, pursuant to all relevant factors and circumstances, the Rules for Water Utilization and Inter-basin Diversions provided for under Article 26 and the provisions of A and B below:

A. Tributaries of the Mekong River, including Tonle Sap, intra-basin uses and inter-basin diversions shall be subject to notification to the Joint Committee.

B. On the mainstream of the Mekong River:

1. During the wet season:

a) Intra-basin use shall be subject to notification to the Joint Committee.

b) Inter-basin diversion shall be subject to prior consultation, which aims at arriving at an agreement by the Joint Committee.

2. During the dry season:

a) Intra-basin use shall be subject to prior consultation, which aims at arriving at an agreement by the Joint Committee.

b) Any inter-basin diversion project shall be agreed upon by the Joint Committee through a specific agreement for each project prior to any proposed diversion. However, should there be a surplus quantity of water available in excess of the proposed uses of all parties in any dry season, verified and unanimously confirmed as such by the Joint Committee, an inter-basin diversion of the surplus could be made subject to prior consultation.

As indicated above any proposed water use in the Lower Mekong Basin shall be subject to "Notification to" or "Prior Consultation with" or "Specific Agreement by" the Joint Committee pursuant to Article 5 of the Mekong Agreement, as summarized below.

Table 2.1 Summary of Provision of Article 5

River	Season	Water Use Type	Provision
Tributaries	Not Specified	Intra-basin use	**Notification** to the Joint Committee
		Inter-basin diversion	**Notification** to the Joint Committee
Mainstream	Wet season	Intra-basin use	**Notification** to the Joint Committee
		Inter-basin diversion	**Prior consultation which aims at arriving at an agreement** by the Joint Committee
	Dry season	Intra-basin use	**Prior consultation which aims at arriving at an agreement** by the Joint Committee
		Inter-basin diversion	Agreed upon by the Joint Committee through a **Specific Agreement** for each project

Source: JICA-WUP Study Team based on the 1995 Mekong Agreement

As shown in the Article 5 matrix above, water use is categorized in terms of (i) source of water; tributary or mainstream, (ii) seasonal; wet or dry season, and (iii) location of use; intra-basin (within the Mekong Basin) or inter-basin (outside of the Mekong Basin). The above Notification, Prior Consultation and Specific Agreement shall contain the water use conditions such as intake location, service area, intake quantity, intake/dam structures, dam operation rules, etc. The Preliminary Procedures for Notification, Prior Consultation and Agreement approved by the Council in November 2002 reflects these various obligations through these three mechanisms:

- **Notification:** Timely provision of information by a riparian country to the Joint Committee on any proposal for a definite use of water according to the format, content and procedures. Notification is required only for uses on the Mekong basin tributaries or for uses on the mainstream only during the wet season.

- **Prior Consultation:** Timely Notification plus additional data and information to the Joint Committee. Prior Consultation is a more rigorous form of communication for proposals for a use of water on the mainstream. Prior Consultation requires the proponent to consult with other riparian countries to explain the proposed use and receive responses with the aim of arriving at an Agreement to proceed supported by a decision by the Joint Committee. The timeframe for Prior Consultation shall be a minimum period of 6 months.

- **Specific Agreement:** A Specific Agreement is the most rigorous process. This is required only when there is a proposal for an inter-basin diversion from the mainstream during the dry season. This provision imposes a duty upon the proposing riparian country to fully describe the proposed use. Such a specific agreement shall be signed/approved by all members of the Joint Committee and set out agreed terms and conditions such as timing, quantity of diversion, etc.

In this connection, Article 6 is raised because of the important role of the Mekong mainstream flows in flood control, various water abstractions, inland fishery, navigation, biodiversity, sea water intrusion control and so on. It is generally said worldwide that the current beneficial use of river water comprises two basic elements:

- **In-stream water use:** fishery, preservation of self-purification of river, prevention of salinity intrusion, preservation of aquatic habits and life, preservation of ecosystem, etc.

- **On-stream water use:** navigation, timber floating, scenic view (outdoor recreation), tourism, etc.

- **Off-stream water use:** water withdrawal or diversion for various purposes of domestic and industrial uses, agricultural developments, hydroelectric power generation, etc.

The intra-basin water use is categorized as the above in-stream, on-stream and off-stream water uses in the Mekong River. On the contrary, the inter-basin water diversion means diversion of water from the mainstream or tributary of the Mekong River system into another river basin.

The in-stream water use is closely related to the environmental flow that has been highlighted worldwide to preserve the river ecologically healthy. The environmental flow requirements need to be analyzed for preservation of natural functions of the Mekong River, considering the respective issues peculiar to the riparian countries. In this connection, the Mekong Agreement stipulates that "riparian countries shall protect the environment, natural resources, aquatic life and conditions, and ecological balance of the Mekong River Basin from pollution and harmful effects" in Article 3: Protection of the Environment and Ecological Balance, and "shall make every effort to avoid, minimize and mitigate harmful effects that might occur to the environment, especially the water quantity and quality, the aquatic (eco-system) conditions, and ecological balance of the river system, from the development and use of the Mekong River Basin water resources or discharge of waste and return flows in Article 7: Prevention and Cessation of Harmful Effects. These stipulations incorporate growing international concerns on what can be done to manage the river flows ensuring the existing water use and future needs as well as maintaining the river health.

2.4 Timeframe of Wet and Dry Seasons

Establishment of the timeframe for the wet and dry seasons, which is stipulated as one of requirements in Article 26, is important to facilitate the procedural rule of Preliminary Procedures for Notification, Prior Consultation and Agreement. Its potential definitions have been tirelessly discussed within MRC as well as the riparian countries, and is now almost for final determination. The Preliminary Procedures for Notification, Prior Consultation and Agreement defines the "wet and dry seasons" as one of the key terms in the Agreement as follows:

> *"**Wet and Dry Seasons:** The dates of the start and end of the wet and dry seasons vary throughout the basin due to the regional variations. According to the preliminary analyses of the relatively long time series of hydro-meteorological data, the wet season may start during mid-May to mid-June and end from mid-November to mid-December. The Joint Committee will decide on the actual dates of the start and the end of the wet and dry seasons, based on analyses by MRC Secretariat together with the National Mekong Committees (NMCs) of long term mainstream flow data."*

Along this line, the Technical Drafting Group 2 (TDG2) for the procedural rule of Preliminary Procedures for Notification, Prior Consultation and Agreement, which is composed of members from NMCs and MRCS, has been discussing this issue since 8th TGD2 meeting held in November 2002. In order to settle the issue, MRCS (Technical Support Division) as well as JICA-WUP and WUP-A made hydrological analysis separately. As a result at the 3rd TDG4 (for the procedural rule of Procedures for Notification, Prior Consultation and Agreement) meeting at Hanoi on 27 June 2003, MRCS proposed the working definition of the wet and dry seasons:

(1) The criteria are as follows:

   (a) The ***onset of the wet season*** shall be the date at which the up-crossing of the mean annual hydrograph intersects the ***median*** discharge; and

   (a) The ***end of the wet season*** shall be the date at which the down-crossing of the mean annual hydrograph intersects the ***mean*** discharge.

(2) For *administrative purposes* and immediate application (for determining application of the processes of notification, prior consultation and specific agreement):

   (a) The ***wet season*** shall be set at ***6 June to 4 November***, and

   (b) The ***dry season*** shall be set at ***5 November to 5 June of the following year***.

The following figure illustrates a comparison between the median and mean discharges of the mean annual hydrographs at 12 hydrologic stations on the mainstream.

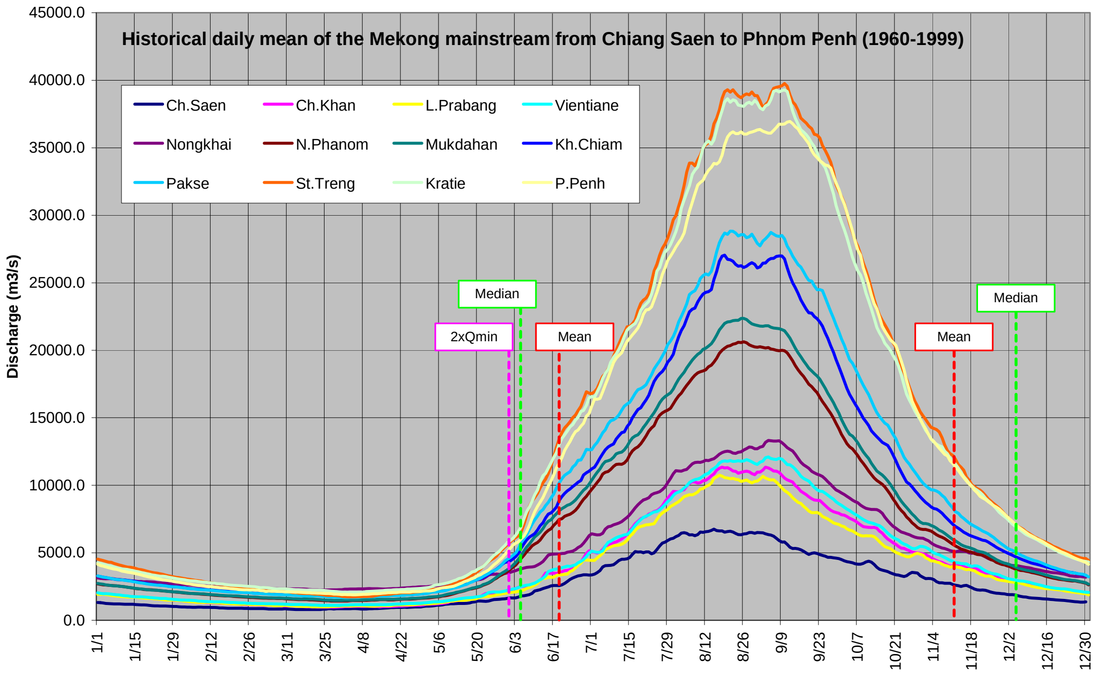


Fig. 2.3 Comparison of Median and Mean Discharges of Mean Annual Hydrographs

However, the meeting has not led to a successful conclusion among all delegations. All delegations agreed that a provisional definition on the wet and dry seasons should be in two parts: (i) for administrative purposes, and (ii) for operational and planning purposes. Some delegations have their preferences on the date of wet season. The provisional timeframe and the preferences from the 8th TDG2 meeting of all delegations is summarized as follows:

Table 2.2 Provisional Timeframe of Wet Season

Country	3rd TDG4 meeting in June 2003	8th TDG2 meeting in November 2002
Cambodia	1 June to 30 November	1 June to 30 November
Lao PDR	1 June to 30 November	15 May to 15 November
Thailand	15 May to 30 November	15 May to 15 December
Vietnam	6 June to 4 November	15 June to 15 November

Source: Minutes of 3rd TDG4 Meeting

Some delegations expressed reservations with respect to the provisional definition on the timeframe for operational purposes expressing that there is a need for more information in connection with other MRC programmes and how to determine the thresholds for the up-crossing and down-crossing limbs of the annual hydrographs and that all relevant factors and circumstances available need to be taken into account. The MRCS's designated staff however believed that without further guidance from the TDG4 members the relevant factors and circumstances on the technical basis have been taken into account to date.

The timeframe is closely related with the procedural rule of Procedures for Notification, Prior Consultation and Agreement. This procedural rule was just agreed on November 30, 2003. Under this rule, establishment of the timeframe for the wet and dry seasons was also agreed with the terms: that the wet season may start during mid-May to mid-June and end from mid-November to mid-December. The Joint Committee will make the final decision on the actual dates of the start and the end of the wet and dry seasons.

2.5 Natural River Flow

2.5.1 General

River waters have been continuously developed for various uses since the olden days to satisfy water use requirements in river basins. Hence, river flow regimes have historically changed according to water resources developments as well as changes of watershed conditions (land use changes such as deforestation, shifting cultivation for upland farming, etc.). Thus the current river flow regime (observed flow) is different from the past one due to the affects of the existing water uses.

Basically, engineering studies for water resources development planning requires natural river flow regime in the objective river basin as the first planning step. The natural river flow is usually defined as the river flow that is not affected by any water usesand water resources development. Along this line, the design natural low flow regime (design low flow) is determined as the basis for evaluating the available surplus quantity of river water for planning.

The current (observed) river flow has been more or less influenced by the existing uses of water stored in reservoirs, released from reservoirs, and abstracted from rivers. The illustration below shows a simplification of relationship between natural flow and observed flow. If the water stored in reservoir is used only for hydropower purpose, then there will be an increase in dry season flows. Several explicit examples on changes in low flow regime in the Mekong River Basin are explained below.

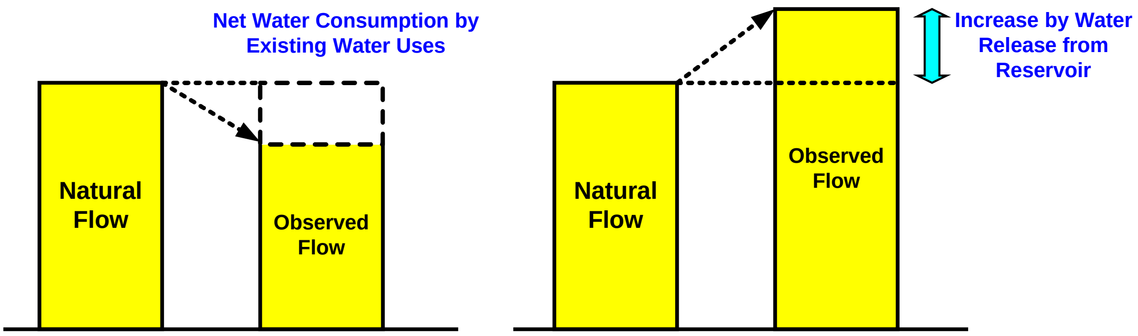


Fig. 2.4 Relationship between Natural Flow and Observed Flow

Changes in low flow regimes in the Lower Mekong Basin have been studied in a separate report: Current Water Use and Changes in Low Flow Regimes on the Mekong Mainstream. The following are the main points from the report.

2.5.2 Nam Ngum River

The Nam Ngum Hydropower Development Project in Lao PDR was implemented in 1985. The Nam Ngum dam has a large reservoir of seasonal flow regulation (4,700 million m^3 of an effective storage). It is expected to enable dry-season flows to be significantly supplied and thus droughts to be alleviated in the Nam Ngum River. Changes of flow regimes of both the Nam Ngum River and the Mekong mainstream due to hydropower generation at the Nam Ngum Dam was examined in the course of the study by use of the observed hydrologic data as well as the dam operation record. Fig. 2.5 and 2.6 show the comparison of mean monthly reservoir inflow and outflow (1979-2001).

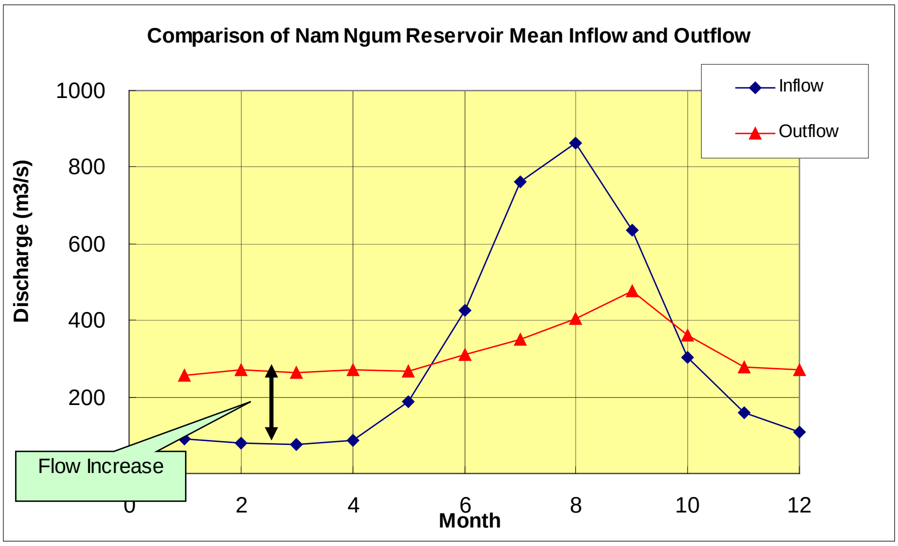


Fig. 2.5 Comparison of Mean Monthly Inflow and Outflow at Nam Ngum Dam

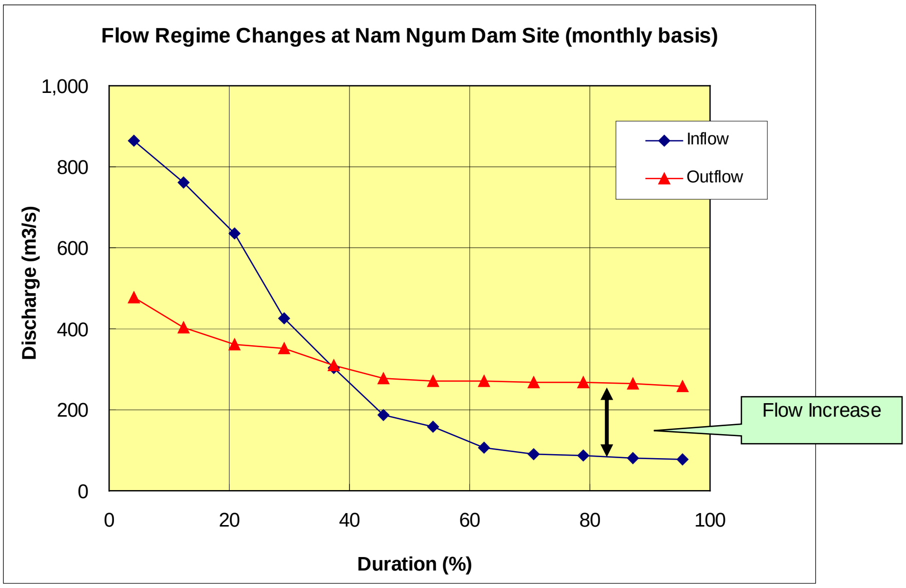


Fig. 2.6 Flow Regulation in Terms of Duration Curves at Nam Ngum Dam

As a result of the operation of Nam Ngum reservoir, there is a significant increase in dry season flows in the downstream reaches of the Nam Ngum River. Fig. 2.7 below shows the comparison of time-series of monthly mean discharge in February in the dry season at the stations in the Nam Ngum River system. Location map of selected stations is schematically shown in Fig. 2.8. As seen below, low flows in February were significantly increased by around 190 m^3/s.

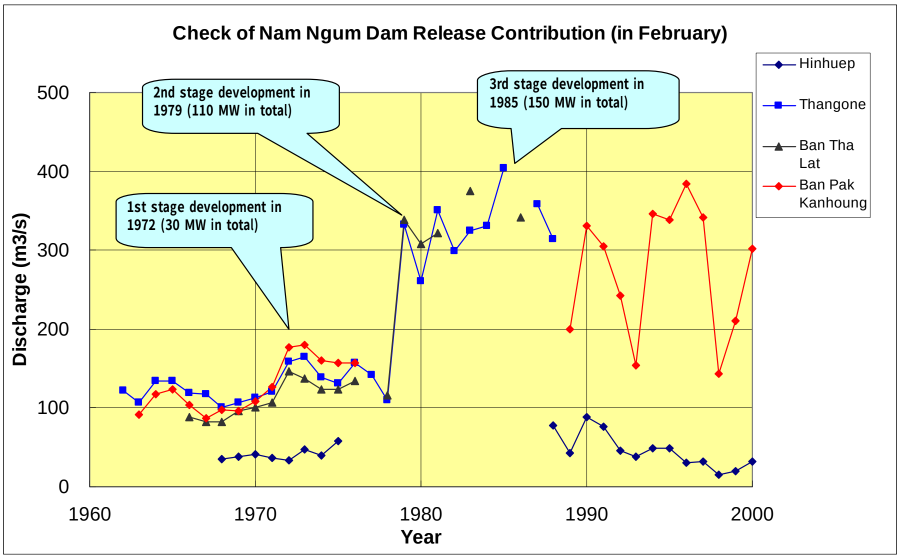


Fig. 2.7 Low Flow Increase in February in the Nam Ngum River

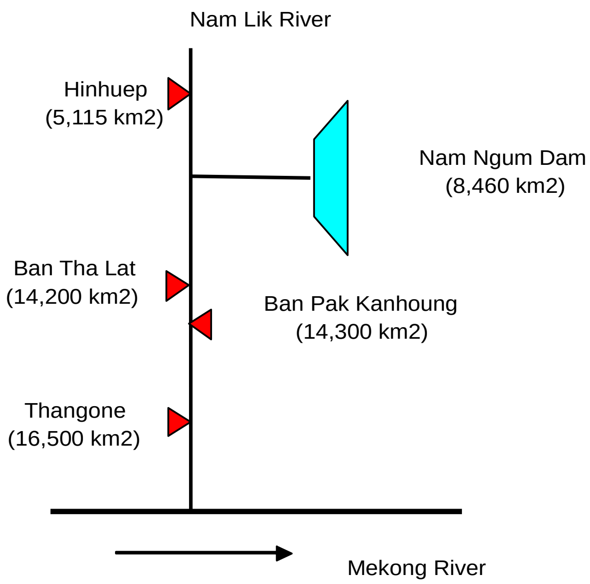


Fig. 2.8 Location Map of Selected Stations in the Nam Ngum River

2.5.3 Mekong Mainstream

The increased low flows of the Nam Ngum River (17,170 km^2) joins the Mekong mainstream. Hence, the low flows in the Mekong mainstream would significantly increase. Changes of low flow regime on the Mekong mainstream were further examined in terms of lateral inflows from the tributaries. The lateral inflows are estimated based on the low flow balance between the hydrologic stations on the Mekong mainstream as illustrated below.

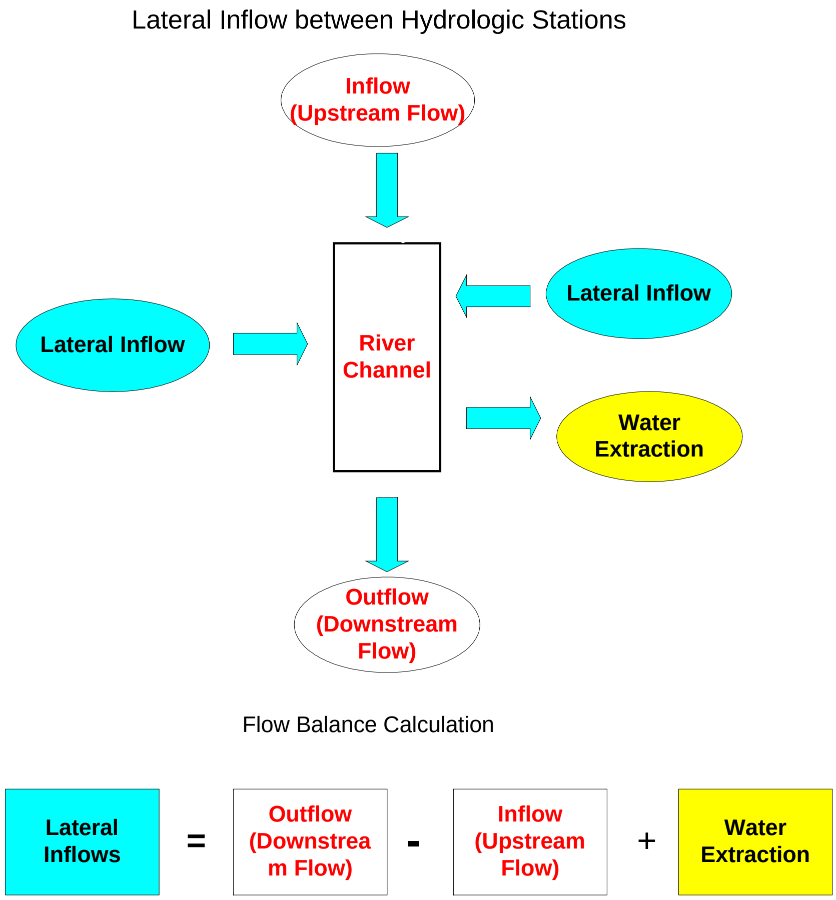


Fig. 2.9 Illustration of Flow Balance Calculation

The Nam Ngum River joins the Mekong mainstream between Nong Khai and Nakong Phanom. Figures below show the comparison of time-series of monthly mean discharges in March at both stations, and the estimated monthly lateral inflows from the contributing area, which is 71,000 km^2.

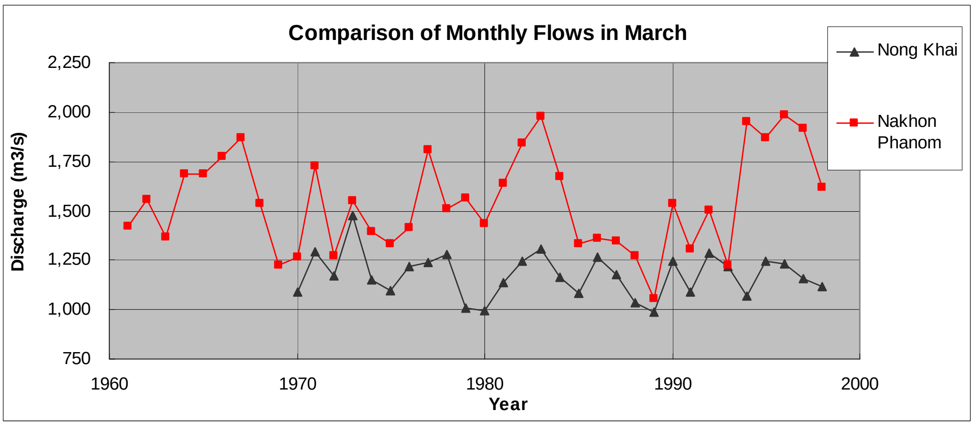


Fig. 2.10 Comparison of Time-series of Monthly Mean Discharges at Nong Khai and Nakhon Phanom

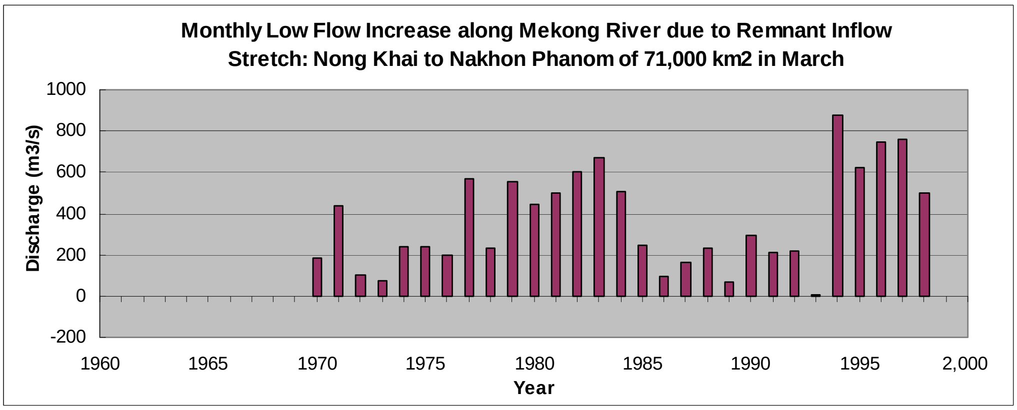


Fig. 2.11 Low Flow Balance in March in the Nong Khai-Nakong Phanom Stretch of Mekong Mainstream

The low flow in the Mekong River is therefore expected to increase due to the low flow increase of the Nam Ngum River. The flow balance result shows the significant increase of lateral inflow in 1979 when the Phase II of Nam Ngum was completed. Sudden increase in 1977 was caused by an unusual release from the Nam Ngum reservoir. However in the period of 1985-1993, lateral inflows become unreasonably smaller although relatively dry years continued in 1987-1993. High lateral inflows in 1994-1997 are resultant from unreasonably high flows at Nakon Phanom from 1994 onwards.

2.5.4 Nam Mun-Chi River

The Nam Mun-Chi River (120,000 km^2) is a tributary in north-eastern Thailand where river flows have been much affected by historic intensive irrigation development and construction of seasonal-regulating large reservoirs from the mid 1960s to early 1970s. Fig.2.12 below shows the comparison of time-series of monthly mean discharges in April in the Nam Mun-Chi river. Location map of the selected stations is illustrated in Fig. 2.13.

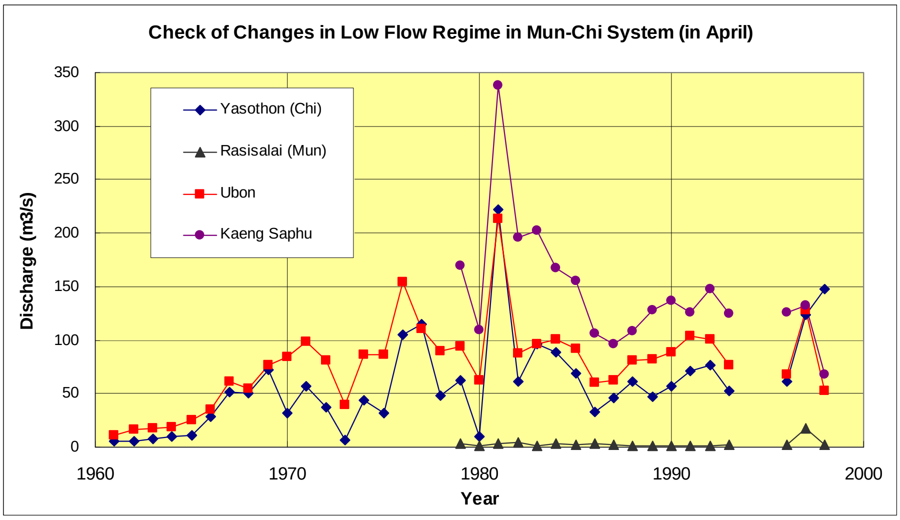


Fig. 2.12 Comparison of Time-series of Monthly Mean Discharges in the Nam Mun-Chi River

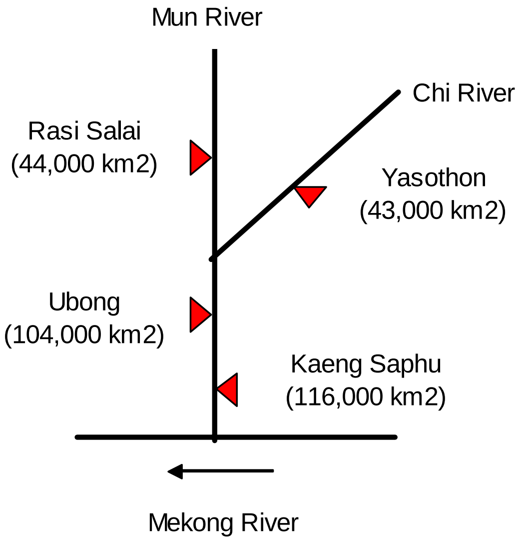


Fig. 2.13 Location Map of Selected Hydrological Stations in Nam Mun-Chi River

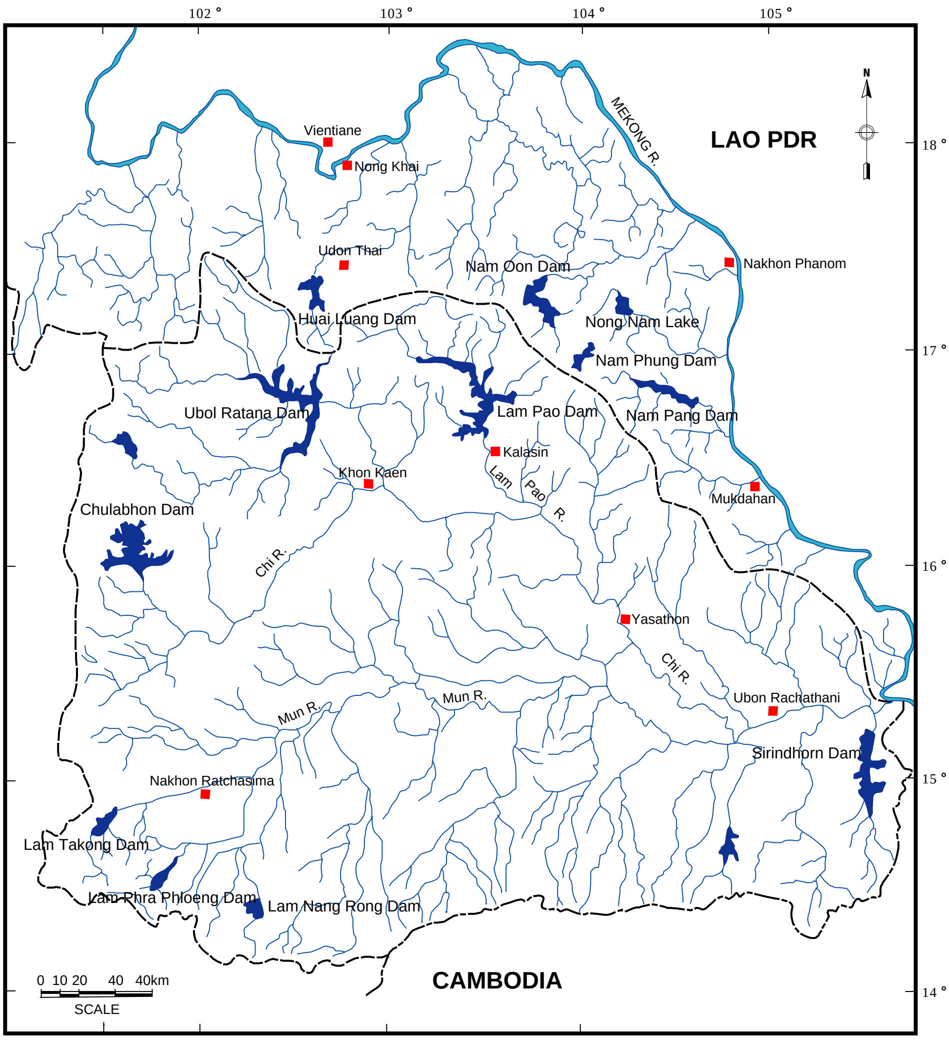


Fig. 2.14 Location Map of Large Reservoirs in Thailand

Almost the same trends are observed at all stations with an exception of the Rasi Salai station on the Nam Mun River where the extremely small and constant flows are seen. From the mid-1960s to the mid-1970s, these three stations show clear upward trends, and from the mid 1980s onwards almost level trends are seen. This significant flow increasing trends are almost coincide with the progress of various water resources developments in the basin as shown below.

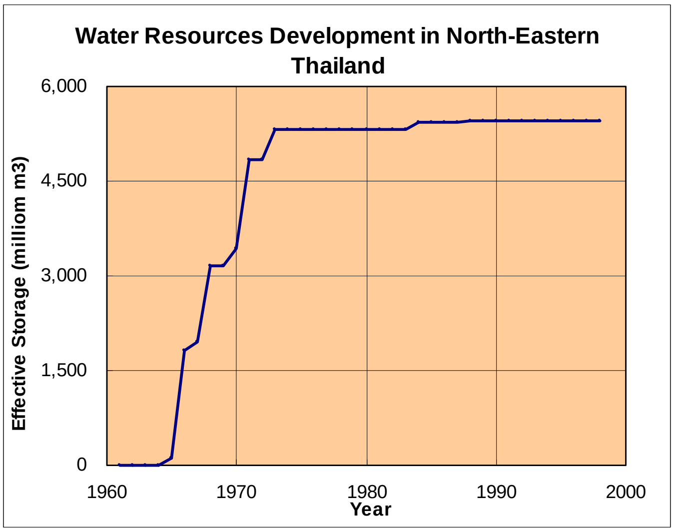


Fig. 2.15 Historic Water Resources Development in North-Eastern Thailand

This upward flow trends are indicative that intensive water resources development made significant impacts on the low flow regimes in the Nam Chi River. Almost stable level trends from the mid-1980s onwards seem to be as a result of water use for basin-wide irrigation. The following table shows the comparison of total capacity of the existing large reservoirs within the drainage areas at both two hydrologic stations. The most likely explanation for such large differences seems to be that the existence of large reservoirs in the Nam Chi River basin causes significantly higher flows in the dry season compared to the dry season flows in the Nam Mun River as compared below.

Table 2.3 Comparison of Large Reservoir Storage in Nam Mun and Nam Chi Rivers

<table>
<tr><th>Hydrologic Station</th><th>Reservoir</th><th>Storage (million m³)</th></tr>
<tr><td rowspan="4">Yasothon (Nam Chi River)</td><td>Ubolratana</td><td>1,695</td></tr>
<tr><td>Chulabhorn</td><td>145</td></tr>
<tr><td>Lam Pao</td><td>1,260</td></tr>
<tr><td>Total</td><td>3,100</td></tr>
<tr><td rowspan="3">Rasi Salai (Nam Mun River)</td><td>Lam Phra Ploeng</td><td>145</td></tr>
<tr><td>Lam Takong</td><td>290</td></tr>
<tr><td>Total</td><td>435</td></tr>
</table>

Source: WUP-JICA Study Team

In Thailand the expansion of dry season irrigation area has been made without reducing the low flow regime on the Mekong mainstream. Many large scale reservoirs have been built on the Nam Mun-Chi River as well as Mekong tributaries to store wet season water for use in the dry season and have not reduced the dry season flows in the Mekong mainstream. In addition, irrigation water abstraction during the dry season in the Mekong Delta has decreased the low flows with serious issues on worsening of seawater intrusion, although without any impact to other riparian countries simply because the delta in Vietnam is in the lowermost basin location. The changes of low flow regime of the Nam Chi River due to seasonal regulation of the Ubolratana multipurpose dam, which has an effective storage of 1,695 million m^3, is indicative, as shown below.

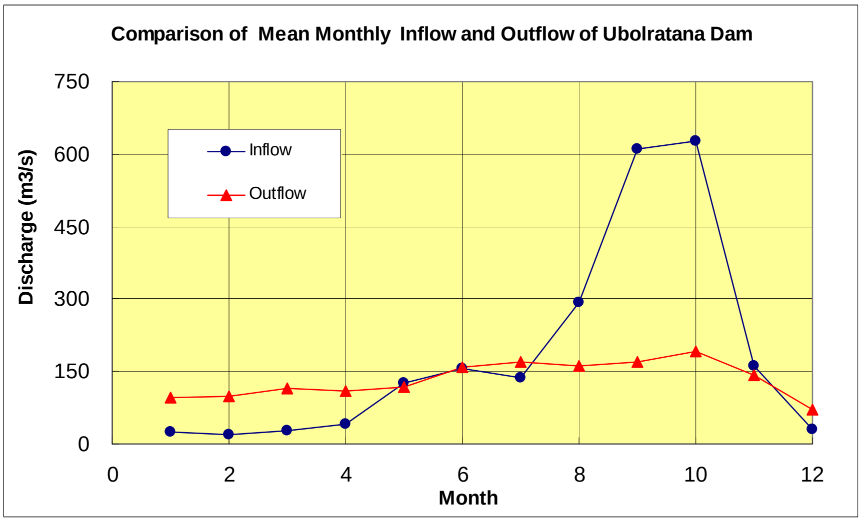


Fig. 2.16 Average Flow Regime Change in Terms of Difference between Mean Monthly Inflow and Outflow of Ubolratana Dam

The average low flow increase in the Nam Chi River from January to April at Ubon was roughly estimated by use of the reservoir operation records of the existing three large seasonal regulation reservoirs; Lam Pao (completed in 1971), Chulabhorn (in 1971) and Ubolratana (in 1966) dams. It is assumed that flows released from the dam are used fully for dry season irrigation and 30% of water use returns to the river as irrigation return flow. The estimated low flow increase is as follows:

Table 2.4 Estimated Average Low Flow Increases in the Nam Chi River due to Seasonal Regulation of Large Reservoirs

(Unit: m3/sec)

	Jan	Feb	Mar	Apr
Monthly Discharge (m^3/s)	46.0	50.2	58.5	45.8
Monthly Volume (million m^3)	123.2	121.3	156.6	118.8

Source : WUP-JICA Study Team

As is apparent from the table above and the flow increase in April at Ubon shown in Fig. 2.12, the estimated average flow increases around 46 m^3/s from both approaches almost coincide with each other. The most likely explanation for such flow increases is that the existence of large reservoirs in the Nam Chi River causes higher flows in the dry season.

Low flow increase of the Mekong mainstream is also examined applying similar flow balance calculation in the river stretch between Khon Chiam and Pakse. The Khon Chiam station is located about 1 km upstream from the confluence with the Nam Mun-Chi River. The contributing catchment of lateral flows is around 126,000 km^2, out of which the Nam Mun-Chi River occupies 95%.

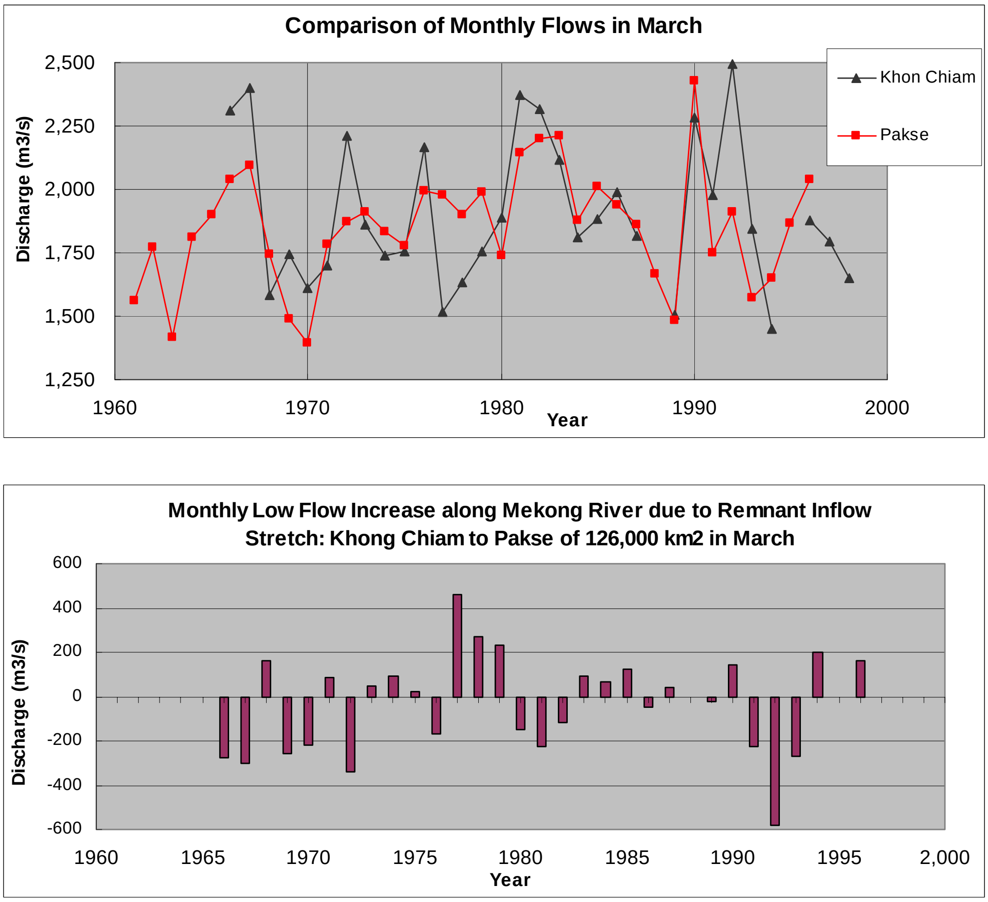


Fig. 2.17 Low Flow Balances in Khong Chiam-Pakse Stretch in March

Due to unreasonably sharper fluctuation of monthly mean discharges at Khong Chiam, the upstream and downstream flow balance inconsistencies have frequently occurred, where the estimated lateral inflow becomes negative. This might be due to errors in rating curves.

2.5.5 Recommendation on the Natural River Flow

Water usage issues in the Lower Mekong Basin are of great importance for the design of Basin Simulation Modeling Package and Knowledge Base being developed under the ongoing WUP-A. This modeling package would need to naturalize the measured hydrological flows. It is however reported that WUP-A has been confronted by difficulties and constraints of the serious lack of historic water usage data (mainly relating to irrigation developments) and sparse information available for effective model calibration.

In general it might be difficult to obtain pure natural flow regimes since human activities are extensive. Hence the historic water use data are very necessary to estimate the natural flow on the basis of the measured flows. The actual current river flow regimes of the Mekong River (observed historical records at the hydrologic stations on the Mekong mainstream) are resulting from the accumulated effects of historic basin-wide water uses. Establishing "acceptable flows" based on "the natural flow regime" is a key factor as stipulated in Article 6. The Agreement for the full utilization of the Nile River signed between Sudan and the United Arab Republic provides that the flow records before the 20th century are assumed to be the natural flow and these thereafter shall be subject to the naturalization processing.

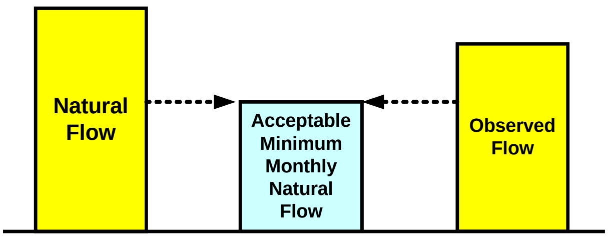
However from the practical points of view, the actual current flow regimes are recommendable as the natural flow regimes for setting out the criteria for determining surplus quantities of water during the dry season on the mainstream taking the following characteristics peculiar to the Mekong River Basin into consideration:

(1) At present the Basin Development Plan (BDP) is ongoing, aiming at development of agreed basin-wide development plan with a balanced mix of social, economic and environmental factors. This plan would be thus formulated and implemented not to infringe on the existing water uses in the entire Lower Mekong Basin. It is very natural that the four member riparian states do not wish to lose or reduce any existing water uses. Thus it seems impractical and unnecessary to establish the natural flow regime.

(2) In the naturalization process by use of the observed flow regimes, it is necessary to set up the starting year for naturalizing the flow records. Before the stating year, the flow records are assumed to be the natural flows. Along this line, it is necessary to gather data/information on the basin-wide historical water usages. However the data available to reliably estimate extensive water usages is very limited so far. At moment the feasibility of naturalizing the measured flows with sufficient accuracy presumably seems low.

(3) In Lao PDR, net increase of mainstream flow in the dry season is estimated around 90 m^3/s, subtracting the dry season irrigation demand of around 100 m^3/s (based on the assumption that approx. 100,000 ha of dry season irrigation with a diversion requirement of 1 liter/s/ha) from the average flow increase of 190 m^3/s due to the water release of Nam Ngum reservoir. In Thailand, the dry season flow was estimated to increase by around 45-60 m^3/s due to the supply balance of reservoirs. In Cambodia, low flow was decreased by around 68 m^3/s as the same assumption is applied to approx. 68,000 ha of dry season irrigation. The preliminary flow balance on the mainstream in the dry season implies that the existing off-stream use (irrigation use in majority) is negligibly small compared to the mean monthly flow of 2,800 m^3/s in April at the Cambodia-Vietnam national border into the Mekong Delta, when the Mekong flows become the lowest.

(4) In reality, it is highly unlikely that the acceptable minimum level of flows would not be determined from the pure natural flows. Further it would not be significant meaning whether determination of the acceptable minimum level of flows is made on the basis of the current flow regimes or the estimated natural flow regimes. The acceptable minimum level of flows shall be practically applied to the current flow regimes.



(5) Considering the historical background of the establishment of the 1995 Mekong Agreement, the technical term "natural" might merely mean the actual flow conditions before construction of a series of seasonal regulation large reservoirs on the Mekong mainstream as planned in the past such as the Pa Mong dam in 1970s. It was said by Dr. Greg Browder in his dissertation paper in 1998 that in the early 1990s, the Mekong River was essentially unregulated and the "existing low water discharge" is close to the natural dry season flow.

(6) The WUP-A developed the Decision Support Framework (DSF), which is intended to be a key simulation tool to support decision making for basin planning and management through assessment of the impacts of development options. In this connection, DSF provides the baseline flow conditions (named the Baseline Scenario) as the comparative base against which the development scenarios can be evaluated. It is defined as having the same climatic

conditions from 1985 to 2000, but with water demands held at year 2000 levels for all years (The time-series irrigation areas in 1985-2000 in the crop model have been replaced by the irrigation area of the year 2000). Existing physical structures such as dams and embankments are also the same as at year 2000 conditions. The flow regimes under the baseline conditions are presumably considered the Mekong natural flow regimes.

(7) The Xiaowan Hydropower Project, a large-scale reservoir type project with active storage capacity of 11,500 million m^3, is under construction on the Mekong mainstream in China. This project will create the first seasonal flow regulation reservoir on the mainstream. This seasonal flow regulation will drastically change the Mekong flow regime especially significant increase of low flows in the dry season (expectedly 555 m^3/s). In this sense, the current flow regimes might be usable as the natural flow before completion of this project.

(8) MRC has just started the program for Integrated Basin Flow Management (to be detailed in the succeeding sections). This project is MRC's new approach for determination of the environmental flows on the Mekong mainstream. The estimated environmental flows are expected to be the acceptable limit of pattern of current flows on monthly basis (substantially applied to the acceptable minimum monthly natural flows) that would contain and guarantee the current water uses.

Nevertheless this application above might not allow the countries with little developments to be given equal development opportunity with countries that already have significant developments (water demand has been very high). In technical viewpoints of the equitable utilization (future water allocation?) of the Mekong flows, clarification and evaluation of historic water usages and/or flow contributions (such as low flow increase by water release from reservoir) by each riparian country would be the starting point that shall be made on the basis of the natural flow regime. It would be practical and idealistic as setting out the starting point under the ongoing BDP programme. It is recommended that a decision on "the natural flow conditions" be clarified and agreed by the Joint Committee earlier in preparation of the draft water utilization rules.

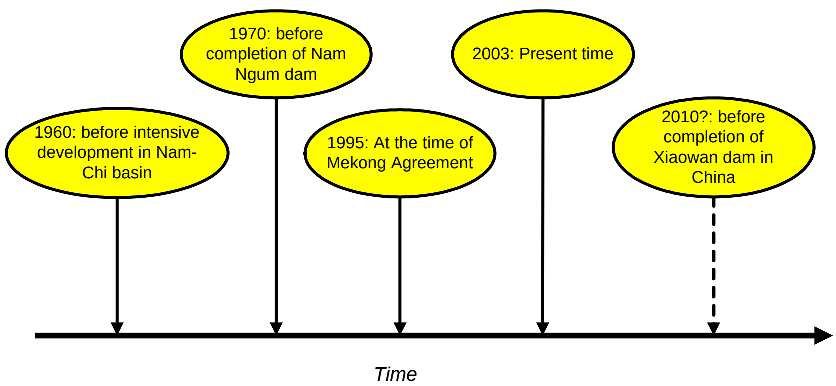


Fig. 2.18 Starting Years for Naturalization of River Flows

2.5.6 An Episode of Controversy on the Natural Flow from Dr. George Radosevich, WUP Legal Advisor

At the Regional Training Workshop of WUP-JICA on Water allocation and Monitoring: International Experiences held in Ho Chi Minh City on 23-25 January 2002, Dr. George Radosevich introduced an episode on the discussions between negotiators from Thailand and Vietnam on what formula should be used to calculate the "minimum monthly natural flow during the dry season" (mathematical approaches), although the negotiators disagreed from each other. The Thai proposed a formula using the minimum of daily flows in a one-month period. For example, if the average daily flows during May ranged from 1,500 m^3/s to 2,500 m^3/s, the Thai formula would yield a value of 1,500 m^3/s. The Vietnamese proposed a formula using average flow for a one-month period. Using the same example, the Vietnamese formula might yield a figure of 2,000 m^3/s. The Thai and Vietnamese also disagreed on whether the flows should be calculated using years with high, mean or low annual discharges. Finally the negotiators decided to let the MRC determine what formula should be used to calculate the minimum dry season flows.

Also Dr. George Radosevich mentions in his paper in 1995 that in examining the hydrographs for highest (1966), mean (1978), and lowest (1992) discharges of the Mekong River at Pakse (apparently the most reliable data collection site with a direct correlation to the data available at Kratie or Stung Treng, hence as reliable a data basis available for projecting flows below Kratie to the Delta) provided by the Mekong Secretariat, it appears that the difference under either approach is ±500 m^3/s.

2.5.7 "Existing Flow Regime" as the Baseline Scenario

The Regional Workshop for the Integrated Basin Flow Management-Rule for Maintenance of Flows on the Mainstream was firstly held on 16-17 December 2003 in Phnom Penh with the participants of all members of the newly formed Technical Review Group (TRG) and TDG5 for the Rule formulation. One of the highlights is to discuss and gain a common understanding of the detailed approach to defining preliminary rules for the maintenance of flows based on the existing water uses and flow regime of the Lower Mekong Basin (LMB). As the baseline flow conditions of LMB, simulated flow data generated from the DSF is recommended for the preliminary rule drafting process. These simulated flows are of time-series of 16 years using the rainfall input data from 1985-2000, the basin condition of which is proposed to be the present state of developments (e.g,. the dams, irrigation systems, land cover, land uses, river channels, other boundary conditions, etc.) in the year 2000. This is because the year 2000 is the most recent year of full records and data in the Knowledge Base in DSF. These data set of flows will describe the "existing flow regime;" that is, the Baseline Scenario as the technical basis for the rule–making, giving a "picture" of the flow variety of the Mekong River.

2.6 Worldwide Concerns on Environmental Flows

The in-stream water use is closely related to "the environmental flows" that have been highlighted worldwide to preserve the river ecologically healthy. Stephen Swales and John H. Harris in 1995 described the key term "environmental flows" as follows:

> *"In-stream flows provided for environmental reasons, sometimes called <u>"environmental flows", are designed to enhance or maintain the habitat for riparian and aquatic life.</u> They may be provided for preserving native species of flora and fauna, maintaining aesthetic quality, maximizing the production of recreational or commercial species for harvest, or protecting features of scientific or cultural interest."*

Besides, Dr. Jackie King, University of Cape Town, South Africa, has introduced to MRC the concept of "environmental flows" as a unifying approach for maintaining river flows as follows:

> *"Water that is left in a river system, or released into it, is to manage the health of the channel, banks, wetlands, floodplains or estuary. <u>When we change the natural pattern of flow, the river will change. We need to decide how much change is acceptable</u> (The objectives). We then need to describe the pattern of flows to maintain that level of change (The Environmental Flow Requirement). <u>Environmental flow is a pattern of flows that will keep the river at a certain level of health</u>. This is pro-active management of river health."*

The presentation on this new approach as well as international experiences for managing river flow to maintain river health was made to the MRC Joint Committee in May 2002. The Nature Conservation Council of NSW (NCC), Australia explains the definition and perception of environmental flows:

> *"Environmental flows are natural releases of water intended to supply the needs of the environment. The timing, volume and quality of environmental flows are all critical aspects and, like the natural flow of rivers, different combinations will provide a different range of benefits for each ecosystem. Environmental flows ensure that the key chemical, geomorphological and ecological process necessary for healthy river ecosystem function. Environmental flows are often perceived by some people as a waste of water. Actually, environmental flows ensure the long term prosperity of the communities and farms which rely upon a healthy river. Flow regulation and over extraction have been the most important factors in the decline in river health and loss of biodiversity in a river."*

The International Union for Conservation of Nature and Natural Resources (IUCN), Switzerland and UK, addressed the benefits of environmental flows and trade-off of benefits:

> *"An environmental flow is the water regime provided within a river, wetland or coastal zone to maintain ecosystems and their benefits where there are competing water uses and where flows are regulated. Environmental flows provide critical contributions to river health, economic development and poverty alleviation. They ensure the continued availability of the many benefits that healthy river and groundwater systems bring to society. The provision of environmental flows is not intended to mimic a pristine river. Identifying and making trade-offs are at the heart of setting and implementing environmental flows. Ideally, the provision of environmental flows should be supported by a comprehensive package of basin-wide management practices and regulations, for example related to land use, water rights and in-stream uses. As new information will become available regularly and river conditions will change, scientists and water managers will need to periodically adapt their environmental flow practices to the new conditions. Therefore the adequacy of an environmental flow should be assessed on a regular basis using the best available information .As responses of plants, animals, resources and people to the flows are monitored and evaluated, environmental flows may need to be amended. This process is known as adaptive management, and forms an essential part of dealing with the trade-offs environmental flow setting and management entails."*

2.7 Methodologies of Environmental Flow Assessment

There is no single best method, approach or framework to determine an environmental flow. According to the paper by Stephen Swales and John H. Harris (1995), a wide variety of methodologies have been developed for assessing the in-stream flow requirements of fish and other aquatic biota to assist in the development of environmental flow considerations. Most of these methods have been developed and applied in North America where altered river flows have jeopardized the continued survival and abundance of commercially and recreationally important fish species, particularly salmonids.

Techniques for assessing the in-stream flow requirements of aquatic biota in rivers fall into three broad categories:

(1) **Historical discharge of "rule-of-thumb" methods (Desktop hydrological analysis methods),** which are based largely on historical flow records and use a fixed proportion of flow. Focus on identifying "the minimum amount of water" which needed to be left in river to maintain the river health. The "minimum flows" are commonly set up in terms of the discharges of non-exceedance probabilities (as a percentage of flow duration curve).

Desktop methods use changes in hydraulic variables, such as those in the "wetted perimeter", the area of riverbed submerged, to define environmental flows. These provide simple indices of available habitat in a river at a given discharge. Some researchers have highlighted the problems of trying to identify threshold discharges below, which wetted perimeter declines rapidly. Given this limitation, these methods are more appropriate to support scenario- based decision makers and water allocation negotiations than to determine an ecological threshold. The Tenant Method is a desktop approach that is relatively inexpensive, quick and easy to apply.

(2) **Habitat analysis methods (Functional analysis methods),** which use a combination of hydrology and hydraulics, and determine useable habitat by transect analysis and hydraulic simulation. Building of an understanding of the functional links between all aspects of the hydrology and ecology of the system. These methods take a broad view and cover many aspects of the river ecosystem, using hydrological analysis, hydraulic rating information and biological data. They also make significant use of experts. Perhaps the best known is the Building Block Methodology (BBM), developed in South Africa. The basic premise of the BBM is that riverine species are reliant on basic elements (building block) of the flow regime, including low flows and floods that maintain the sediment dynamics and geomorphological structure of the river. An acceptable flow regime for ecosystem maintenance can thus be constructed by combining these building blocks.

(3) **In-stream habitat modeling methods,** which determine habitat preference curves for species and model how changes in discharge affect habitat availability. The most commonly applied method is the In-stream Flow Incremental Methodology (IFIM) developed by the US Fish and Wildlife Service. However, this technique has been widely criticized by fisheries scientists as being ecologically simplistic and lacking validation.

Within these general categories, a wide variety of different methods have been developed and applied over the last few decades. However, as yet there is no one tried and tested standard technique for assessing the in-stream flow needs of fish and other in-stream biota that is suitable for all situations. All of the techniques so far developed have specific conditions and geographic regions. All of the flow assessment methods have their own proponents and critics.

Many early application of environmental flow setting were focused on single species or single issues. More and more methods now take a holistic approach that explicitly includes assessment of the whole ecosystem, such as associated wetlands, groundwater and estuaries. These also account for all species that are sensitive to flow, such as invertebrates, plants and animals, and address all aspects of the hydrological regime including e.g. floods, droughts, and water quality. A fundamental principle is to maintain natural variety of flows. Generally, holistic approaches make use of teams of experts and may involve participation of stakeholders, so that the procedure is holistic in terms of interested parties as well as scientific issues. The advantage of the expert team approach is its flexibility and consensus building amongst experts who come to the best solution based on the data and model results available. These methods and approaches are normally incorporated into a wider assessment framework that identifies the problems, uses the best technical method and presents results to decision-makers. Along this line, the Downstream Response to Imposed Flow Transformation (DRIFT) was developed in South Africa. Similar to the BBM it forms a more holistic way of working as it addresses all aspects of the river ecosystem. It is a scenario-based framework, providing decision-makers with a number of options of future flow regimes for a river of concern, together with the consequences for the condition of the river. The DRIFT has four modules to determine a number of scenarios and their ecological, social and economics implications. It is often said that its most important and innovative feature is a strong socio-economic module, which describe the predicted impacts of each scenario on subsistence users of the resources of a river.

Illustration below shows the holistic approach for an environmental flow assessment. Scenarios showing trade-offs shall be assessed in terms of their wider socio-economic implications. Ultimately, society chooses which scenario is most acceptable, and in this way identifies a river's desired future condition. The flows described in the chosen scenario will maintain that desired condition, and will become the environmental flow for that river. They are however unique to each river.

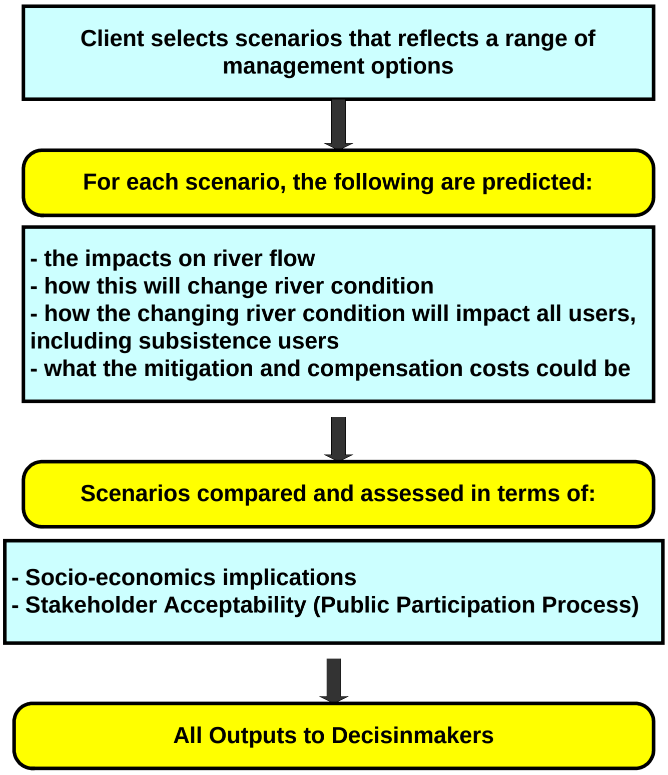


Fig. 2.19 Environmental Flow Assessments in Decision-making Process

2.8 MRC's New Approach of Integrated Basin Flow Management (IBFM)

Having increasing concerns within MRC about environmental flows in the above and as background to the preparation of rules for the maintenance of flows, MRC thought that clearly the DRIFT method was of great potential and it is an opportune time to try to set up the Mekong environmental flows by maximum use or integration of many outcomes of the ongoing and completed MRC programmes. The following are widespread concerns and opinions through MRC workshops:

(1) It is an inescapable fact that we cannot extract water from rivers without causing at least some alterations in the associated aquatic ecosystems. These alterations can be of negligible impact, or they can produce changes that threaten the very existence of the ecosystem. Certainly, in Australia we have proven beyond doubt that we have damaged the ecosystems of some rivers to the extent that remedial action is required. Around the world in the past twenty or so years, a consensus has emerged that if we want our rivers to continue to meet the many needs of our communities then water must be allocated for the environmental health of the river itself (Brian Haisman, Case Study: Environmental Flows and Water Caps in the Murray-Darling Basin, Regional Workshop on Water Allocation and Monitoring, 2002).

(2) In most developed countries, there is a reasonably wide-ranging body of ecological knowledge on the status of biota in regulated rivers upon which to base management decisions. Even in those countries which lack a long history of research into the ecology of their regulated rivers, there is still extensive anecdotal and circumstantial evidence linking declines in aquatic communities such as native fish with the effects of river flow regulation. One of the primary reasons today for the continued widespread degradation of

environmental conditions in streams and rivers throughout the developed world is the inadequate input, transfer and application of ecological knowledge into decisions concerning the management of waters and their resources (Stephen Swales and John H. Harris, The Expert Panel Assessment Method: A New Tool for Determining Environmental Flows in Regulated Rivers, 1995).

(3) A successful approach to environmental flows needed to be more holistic, aiming to manage the whole physical and biological environment rather than just the fish. It is not simply the amount of water flowing down a river that maintains a healthy river. The seasonal pattern of discharge is important (low flows in dry seasons and high flows in wet seasons) and the variability in flow. It is the flow regime that is important, including spatial and temporal variability at a range of scales (The EP-WUP Regional Workshop on TDA, SPA and Flow Management Concept Paper, 2003).

(4) What science and engineering can, and should, provide is the basis for an informed decision. That is if you take “x” amount of water the consequences will be “y”. So rather than providing a single recommended flow regime, the technical community needs to be able to provide a range of scenarios for different levels of water use or water abstraction and the likely ecological and social consequences of each. Decision makers can then select from the scenarios on offer or suggest alternatives which can be evaluated by the same technique used to generate the initial suite (The EP-WUP Regional Workshop on TDA, SPA and Flow Management Concept Paper, 2003).

In the light of such increasing concerns as well as due considerations of the complexities of the Mekong environment, particularly the high levels of biodiversity, and the large human population with livelihoods directly linked to a range of riverine natural resources including insects, plants and fish, MRC prepared to start the program for the Integrated Basin Flow Management (IBFM). The Global Environment Facility (GEF) of the World Bank-implemented WUP Start-up Project is the main provider of funds for the IBFM.

The implementation of IBFM is intended basically in two phases:

(1) Phase 1 is for implementation of an **“**Interim Integrated Basin Flow Assessment” resulting in an Interim Flow Plan (IFP) of low confidence. This phase is based on an “expert panel” approach to carry out a rapid scientific and social analysis and assessment of the response of a number of key natural resource attributes of the Mekong basin to probable changes in the flow regime. The approach is based on available data and knowledge only enabling presentation of a recommended flow plan. A number of flow regime scenarios will be assessed in terms of the environmental, economic and social implications to enable the decision-makers to negotiate the final selection.

(2) Phase 2 will provide a **“**Comprehensive Integrated Basin Flow Assessment” which is a long term MRC activity designed to provide higher confidence flow regime recommendations based on detailed field studies and the experiences gained in Phase 1. The final goal is determination of a Comprehensive Flow Plan (CFP).

Noticeable points of the implementation of IBFM are:

(1) The IBMF will provide the information required to determine just what “acceptable flows” could mean from a broad physical, biological and social perspectives. Since different development options will affect the flow regimes and river condition in different ways, three interim IBFM flow regime scenarios will be developed for negotiations on the Interim Flow Plan (IFP) depending on the quality of information and knowledge available from the three aspects above.

(2) The outcomes of IBMF will be the foundation for establishing the mainstream flow rules and formulating the BDP. The recommended IFP, although it might still be of low confidence with a large margin for error, will be integrated into the drafting of the “Technical Rules for Maintenance of Flows on the Mainstream” (by Technical Drafting Group 5 (TDG5) under WUP Working Group 3), which is intended finally to obtain the endorsement of the MRC Council in October 2004 with provision of the Comprehensive Flow Plan (CFP).

(3) Establishment of the relationship between the flow regimes and the economic and social implications and attributes in their specific discipline is considered as the most important.

(4) Both the Knowledge Base and Impact Analysis tools to be built in the Decision Support Framework (DSF), being developed under the ongoing Component A of WUP, will be used to evaluate environmental, economic and social impacts of different flow regimes resulting from a variety of development scenarios under the planning framework by BDP.

(5) A holistic approach is introduced confronting the environmental flow assessments as a “Mekong method.” Basically this approach aims at defining what amount of flow regime change is socially, economically and ecologically acceptable. This method contemplates the four riparian countries to allow free discussions of the scenarios, creation of additional scenarios if required, and production of flow details on the chosen scenario that can be translated into the draft rule. It will require vigorous debates and discussions within the four riparian countries to achieve mutual understandings and interdisciplinary consensus on the recommendation of Integrated Basin Flow Plan from different flow regimes. In this sense, good and effective management of scientific panels and planned workshops would be the milestone for the IBFM goal.

(6) The “expert panel” approach implemented in Phase 1 requires bringing together a broad, balanced multi-disciplinary team of international and riparian specialists that must together have the skills and background to enable discussion, evaluation and recommendation based data from at least the following disciplines: social sciences, invertebrate ecology, fisheries ecology, aquatic botany, hydraulic modeling, geomorphology/sedimentology, water quality and economics.

(7) An “in-house” team at MRC will implement the IBFM activities. The Head of WUP Working Group 2 at MRC will be the Team Leader for the IBFM activities. He will collaborate mainly with the IBFM Manager on the day-to-day basis and the Scientific Environmental Flow Advisor on the part-time basis. Dr. Jackie King is appointed as the Advisor. The IBFM Manager who will be recruited will manage and integrate the work of a multi-disciplinary team of natural resources management specialists.

(8) Options for national water resourced development proposals to be developed through the BDP process could be evaluated using the Comprehensive Flow Plan (CFP) that will be agreed upon after the IBFM activities.

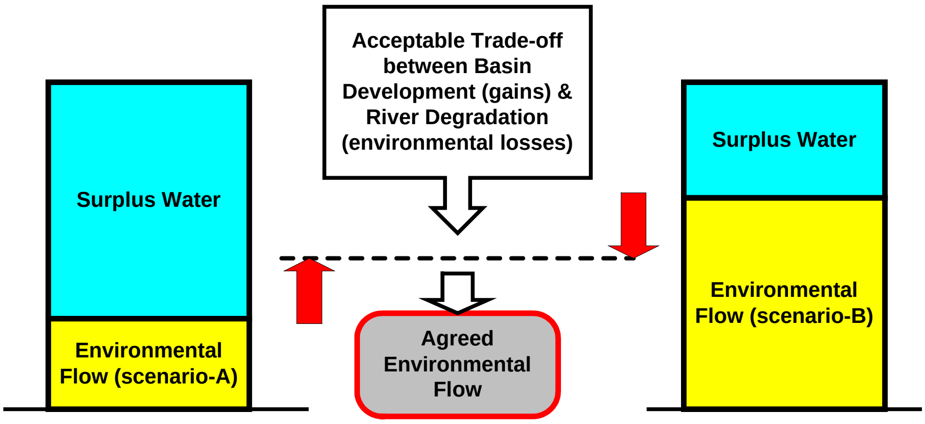


Fig. 2.20 Environmental Flow Assessment as a Mekong Method

Agreed Mekong Method for Setting Environmental Flows:

Through the extensive discussions with the World Bank from March to July 2003, the approach and timeframe of IBFM was agreed. Consequently, IBFM is to be carried out in three phases:

Phase 1: To develop a common understanding and mutually agreed initial flow regimes

Phase 2: To develop an Interim Flow Plan (IFP)

Phase 3: To develop a Comprehensive Flow Plan (CFP)

Phase 1 is to provide a rapid interpretation of what is "acceptable" with respect to Article 6. Phase 1 will be implemented in a way of simple and speedy based largely on hydrological statistics to meet the end of 2004 deadline for the flow rules preparation. It is based on a key assumption that the four riparian countries do not wish to lose or reduce any existing water use, whether in-stream, on-stream or off-stream, or to experience higher levels of adverse impacts with respect to the six key trans-boundary issues; namely, (i) water quality deterioration and sedimentation; (ii) fisheries productivity and ecosystem functioning; (iii) river bank erosion; (iv) obstruction to navigation; (v) inadequate dry season flow; and (vi) flooding, identified through previous work by WUP Working Group 2. Therefore, the initially agreed minimum flows are expected as based on the existing flow regime. The implementation of Phase 1 is divided into two sub-phases: Phase 1a, which aims to develop a common understanding of basin hydrology; and Phase 1b, Preliminary analyses leading to initial rules for maintenance of flows on the mainstream. Expected outcomes of Phase 1a are as follows with maximum use of the Knowledge Base within the MRC's DSF:

(1) Agreed climate, hydrological and hydraulic input data for flow simulation (17-20 years)

(2) Agreed assessment sites to be used later as monitoring points

(3) Simulated and approved non-tidal river flows (the agreed initial flow regime) for probabilistic analysis

(4) Accepted understanding of the hydraulics of floodplain and Tonle Sap inundation, and saline intrusion in the delta

(5) Agreed relationship between the Mekong flow and Tonle Sap inundation

Phase 1b will establish the agreed initial monthly minimum flows and Tonle Sap reversal flows through further analyses by use of the agreed outcomes of Phase 1a. The initial monthly minimum flows will be proposed for both aspects of planning and operational purposes.

Phase 2 will start almost in parallel with Phase 1 and provide a more holistic assessment of the likely social, economic and ecological consequences of particular flow regimes, enabling revision where necessary of the initial definition of acceptable flows established by Phase 1. With the collaboration of BDP, a range of basin development scenarios will be selected that describe realistic trends in the level of basin development and through analyses by the DSF basin simulation model on how these developments may change or impact the mainstream flow regimes of the Mekong River. Each scenario will be evaluated in terms of its ecological, social and economic implications. These will be presented to the countries to enable individual country, and then joint decisions, on which scenarios and optional course of action are acceptable. The one or more acceptable scenarios will identify the flows required in the mainstream (Interim Flow Plan: IFP), to meet the requirements of Article 6, under the assumption of allowing/requiring the rules to be periodically reviewed and amended where necessary. Highlight of Phase 2 is to choose a level of river change that is a mutually acceptable trade-offs between basin development and river condition (a decision made by the four riparian countries based on recommendations by the Review Committee presented to the Joint Committee and eventually the Council of MRC). The Review Committee will be established comprising high-level technical participants from all NMCs with a mandate to negotiate and discuss technical issues.

Phase 3 will provide a Comprehensive Flow Plan (CFP) through research-based holistic approach. The Review Committee will identify modifications and additions that they consider necessary to amend the mutually agreed IFP established in Phase 2. It is anticipated that subsequent reviews of acceptable flows will be made from time to time, including at the conclusion of the comprehensive flow investigations to be conducted by the MRC Environmental Program in Phase 3. Phase 3 will be augmented by additional data collected as a result of this program, with the benefit of identified data gaps and uncertainties highlighted in foregoing two phases, and also data collected via implementation of monitoring programs to meet operation requirements of the Mekong Agreement for monitoring of mainstream flows. Overall schedule is shown below.

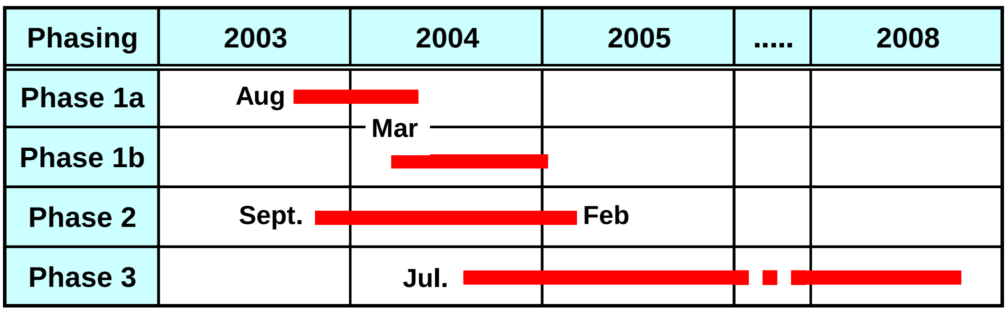


Fig. 2.21 Schedule of MRC Approach for Setting Environmental Flows

2.9 Surplus of Water

2.9.1 Term of Surplus Water in the Agreement

The term of "Surplus Water" is stipulated in the following articles:

Article 5. Reasonable and Equitable Utilization

B. On the mainstream of the Mekong River:

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2. During the dry season:

a) ----------------------------

b) Any inter-basin diversion project shall be agreed upon by the Joint Committee through a specific agreement for each project prior to any proposed diversion. However, should there be a surplus quantity of water available in excess of the proposed uses of all parties in any dry season, verified and unanimously confirmed as such by the Joint Committee, an inter-basin diversion of the surplus could be made subject to prior consultation.

Article 26: Rules for Water Utilization and Inter-Basin Diversions

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2) Establishing the location of hydrological stations, and determining and maintaining the flow level requirements at each station;

3) Setting out criteria for determining surplus quantities of water during the dry season on the mainstream;

The concept of surplus water as well as the complex concepts stipulated in Article 6 might be strongly influenced by the historical context. The Agreement had been discussed for the period from 1992 to 1994, and was established in 1995. For this period a series of reservoir development schemes on the mainstream might still be a major concern in the water resources development of the Lower Mekong basin. From this context, a dynamic process was proposed to share the surplus water to promote the optimum utilization. The Committee will evaluate the data going into and during the dry season, and make adjustments according to the natural flow and discharge occurrences of that dry season, allowing for optimum utilization and cooperation among the riparian countries. It might be a dynamic, practical and operational decision-making process that takes place prior to the onset of the dry season in each year. On the assumption that a series of reservoirs would be constructed on the mainstream, the above-mentioned process could well function by judging from the reservoir's storage levels as significant indicators before the onset of the dry season. Otherwise, the real-time reliable flow monitoring at the principal stations and data processing shall be indispensable for such kind of decision-making.

2.9.2 Basic Idea of Surplus of Water (before Introduction of Environmental Flows Concept)

The four riparian states would not wish to lose or reduce any existing water use. The surplus quantity of water is theoretically obtained as follows:

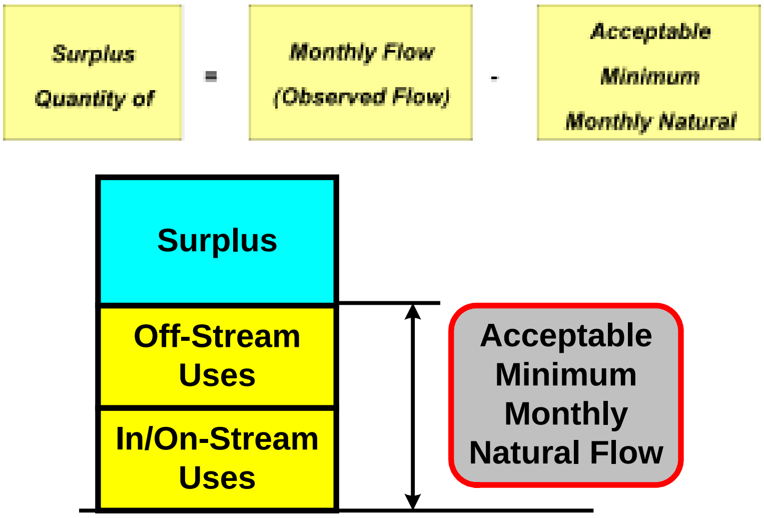


Fig. 2.22 Simplified Definition of Surplus Quantity of Water

The actual water utilization process is however much more complicated since the several representative monitoring-stations are located on the mainstream, and the acceptable minimum monthly natural flow shall be estimated in each segment between the stations adjoining each other. Furthermore the lower stations will be affected by the existing and proposed water uses and their return flows in the upper segments. Thus, in order to establish the water utilization programme and to revise it for the newly proposed water use, some optimization for the water utilization shall be made by the basin model simulation. The acceptable minimum monthly natural flow would increase according to the approval of new water uses (in particular dry season water uses in tributaries with issuing only the Notification as shown in Table 2.1). As a result, the surplus quantity of water decreases.

Key points to be noted in view of technical considerations on the surplus quantity of water are as follows:

(1) The surplus quantity of water derived at some location means not a whole available water at this location but the total available water in the entire upper reaches. In other words, the estimated surplus quantity of water at this location already includes to some extent the surplus water at the upper locations. The surplus quantity of water at this location is also already allocated to some extent at the downstream reaches.

(2) Thus quantification of the surplus water in the entire Mekong River basin shall be accounted for at the downstream end location of the Mekong River, preferably at both the hydrologic stations of Tan Chau on the Mekong and Chau Doc on the Bassac Rivers where the total inflow into the Mekong delta in Vietnam shall be measured and monitored.

(3) If the quantity of surplus water is evaluated in the entire Mekong basin, it will be allocated to the riparian countries according to the agreed proportions from the principle implicitly stipulated in Article 5: Reasonable and Equitable Utilization of the Mekong Agreement. (However, at present, the four riparian states had not agreed on any water allocation; presumably, they had agreed to negotiate more specific agreeable water allocation in the future.)

2.9.3 Relationship between the Surplus of Water and Monitoring Stations

As explained above, the surplus of water estimated at some station is not always the total amount of available surplus water. It already includes part of the surplus of water at the upper stations. For easier understanding of this, a simplified explanation was made at the Regional Training Workshop for Integrated Water Management in the LMRB by WUP-JICA in January 2003, as follows:

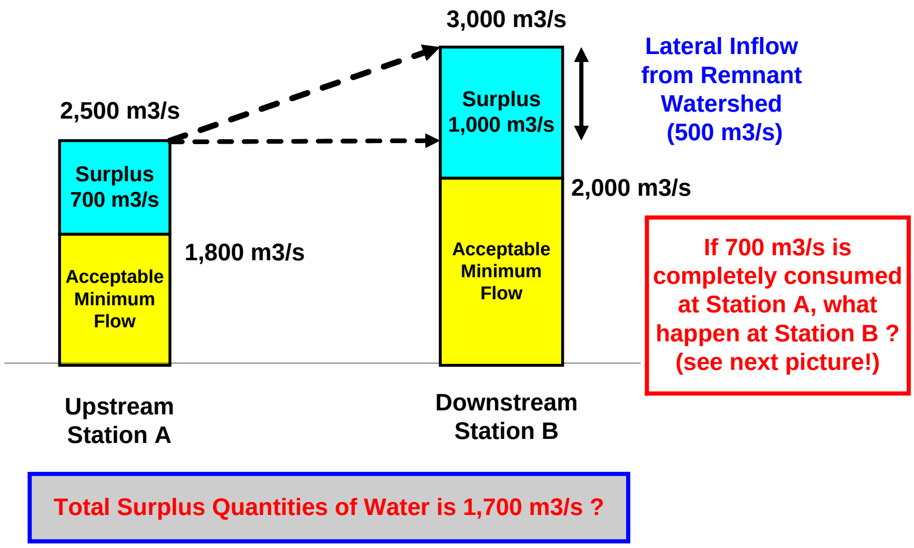


Fig. 2.23 Picture of Workshop Presentation (1)

There are two stations on the mainstream here; upstream station A and downstream station B. Mean monthly discharges in a month in the dry season are assumed 2,500 m^3/s and 3,000 m^3/s respectively. Lateral inflow from the remnant area between stations is thus 500 m^3/s. If the acceptable minimum monthly natural flows are set up as shown in the picture above. The surplus of water becomes thus 700 m^3/s at A and 1,000 m^3/s at B stations. This picture asks why the total surplus of water becomes 1,700 m^3/s. The next picture below also asks: if 700 m^3/s at A station is completely consumed, what happened at B station. The question is whether or not the 1,000 m^3/s at B station still remain unchanged.

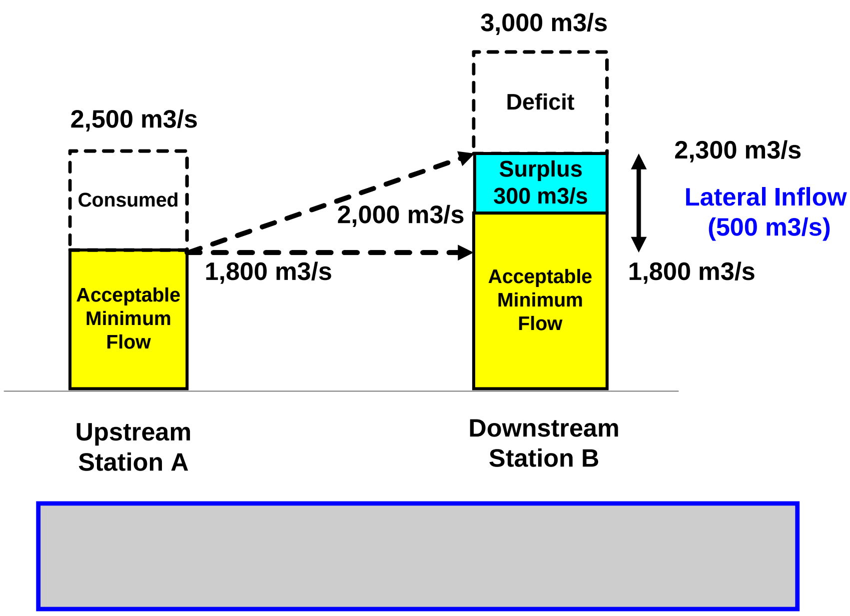


Fig. 2.24 Picture of Workshop Presentation (2)

The water balance after complete use of the surplus water at A station is 1,800 m^3/s. Total flow at B station becomes 2,300 m^3/s. As a result the surplus water becomes only 300 m^3/s (=2,300 – 2,000). The total surplus water in this case is 1,000 m^3/s (consumed 700 m^3/s at A + available 300 m^3/s at B), which is equal to the estimated surplus water at B in advance. The next picture below asks: If one station is added between both stations, will the total surplus water increase or not (700 + 800 + 1,000 = 2,500 m^3/s?). Flow conditions are the same as above.

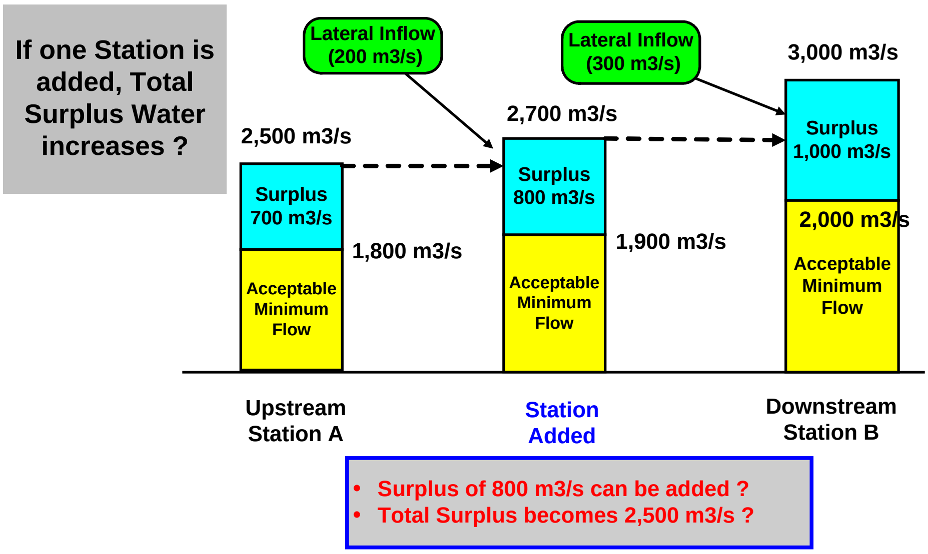


Fig. 2.25 Picture of Workshop Presentation (3)

As indicated below, if 700 m^3/s at A is completely consumed, the discharge at the added station is estimated as 2,000 m^3/s (=1,800 at A + lateral inflow 200). In case the acceptable minimum monthly natural flow is 1,900 m^3/s, the surplus at the added station becomes 100 m^3/s (= 2,000 - 1,900). Further if 100 m^3/s is completely consumed, then the surplus at B becomes 200 m^3/s (= 1,900 at added station + lateral inflow 300 -2,000).

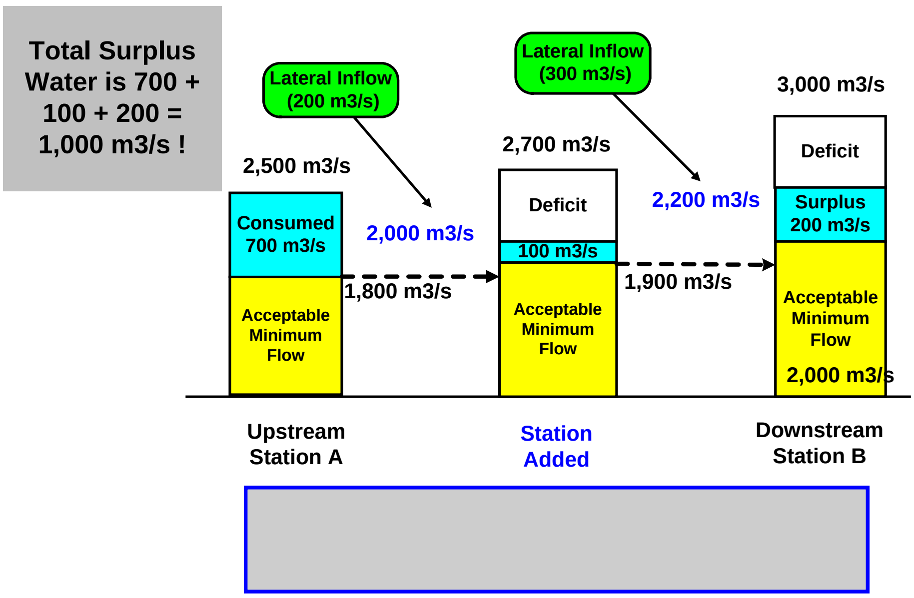


Fig. 2.26 Picture of Workshop Presentation (4)

The total surplus of water is still 1,000 m^3/s (= consumed 700 at A + consumed 100 at added station + available 200 at B). This is also equal to the estimated surplus of water at B in advance. In summary it appears that the surplus quantity of water estimated at downstream station means the total quantity of surplus of water in the whole upper reaches.

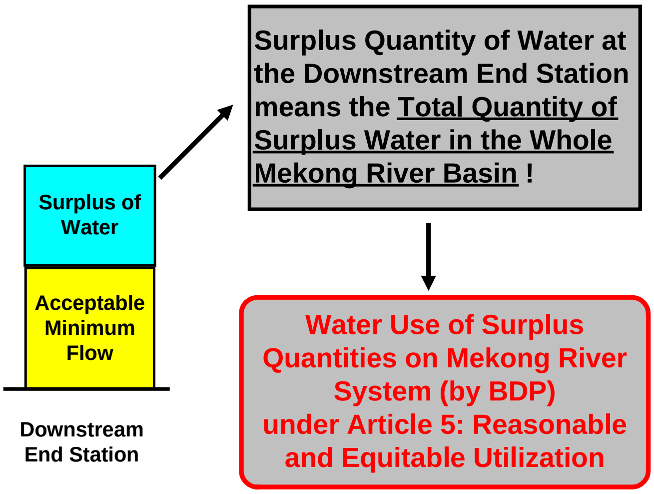


Fig. 2.27 Picture of Workshop Presentation (5)

2.9.4 Basic Idea of Surplus of Water (after Introduction of Environmental Flows Concept)

MRC has launched the new approach for setting up the acceptable monthly minimum natural flow in terms of highlighted environmental flows in the Mekong River. In this process a number of flow regimes are evaluated through a holistic multi-disciplinary approach for final selection by decision-makers. These regimes would be provided by the MRC's DSF simulation based on a range of development scenarios for different levels of water use or water abstraction and the likely ecological, social and economical consequences of each. Such development levels (options) will be subject to due consultation with the NMCs and to final selection by the MRC Council.

As mentioned earlier the environmental flows are to be determined based on negotiations on the acceptable balance (trade-offs) between development and protection of river conditions reflecting different engineering, economic, ecological and social implications. Such negotiations will be made on the flow regimes that will allow sustainable development, utilization, conservation and management of the Mekong River Basin water and its resources (1995 Mekong Agreement). The BDP Inception Report refers to "scenarios" as being a hypothetical combination of events and physical conditions, depending on possible future conditions. In the BDP context, this has been interpreted as a description of events and conditions that could possibly happen resulting from implementing the various basin's development plan options such as higher irrigation demand growth with 10% increase of the current dry season irrigation areas in Thailand and Cambodia. Therefore the negotiated acceptable minimum monthly natural flow will already include future water uses (both consumptive and non-consumptive or in-stream use). In this respect, the surplus water estimated would be a temporal usage. Moreover, as far as an individual development project would not modify flows beyond the agreed flow limits, the acceptable minimum monthly natural flows will remain unchanged.

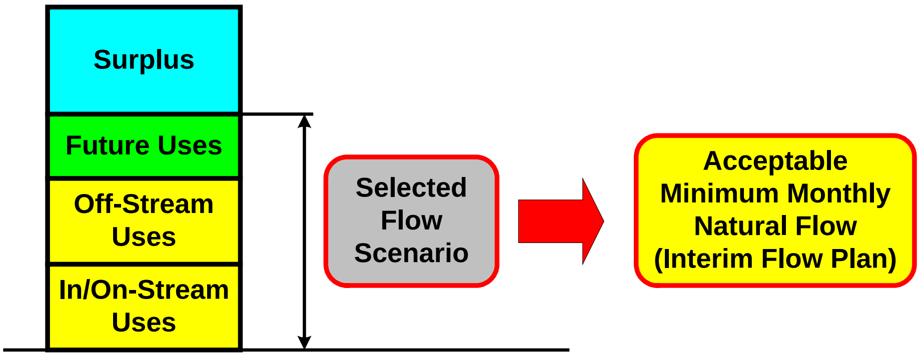


Fig. 2.28 Simplified Definition of Surplus Quantity of Water under Environmental Flow Approach

2.10 Outcomes of Fishery Program within MRC

In the Mekong River, inland fisheries management would be beyond doubt the key factor for assessing environmental flow requirements. Especially, Cambodia is economically almost fully dependent on inland fisheries, which support a thriving industry of great economic and social importance. Fish communities are generally acknowledged to be a good indicator of overall environmental quality or river "health", and respond to direct and indirect stresses of the entire aquatic ecosystem. Along this line, intensive studies and surveys on the fisheries management in the Lower Mekong Basin from the aspects of fish biology (fish migrations of significant human food species, etc.) as well as social importance (social surveys on fish catch, etc.) have been challenged under the ongoing Fisheries Programme (FP) within MRC. Outcomes of the Programme would undoubtedly provide valuable data and information for the environmental flow assessment. Desirable outcomes and information so far available for use are summarized below.

2.10.1 Importance of Fisheries in the Mekong River

The Mekong with its bounty of fisheries and other groups of freshwater animals (both in amount and number of species occurrence or diversities) stands number 3 in the world as having the highest number of freshwater fish species and number 4 in terms of fish productivity (tonnage caught). There are 1,200 species of fish found in the Mekong recorded to date. Many of these species are indigenous to the Mekong. There are many species on which the people of the basin have strong sentiment, and place high value for their existence. The recent estimate of the freshwater fish production based on consumption is 2 million tons per year. The freshwater capture fishery in the Mekong basin is one of the single most important commercial and subsistent economic activities – supply of food, employment, economic activities, and sources of other livelihood for people of the basin, a majority of whom live in the rural areas. It is estimated that most of the 12 million rural households earn their living by rice farming and fishing, with estimated 40 million rural dwellers active in fishery activities. Captured fishery is the most important element in rural households in terms of income nutrition and income generation. Approximately 71% of rural households (or 2.7 million people) in Lao PDR rely on fishing at a varying degree as livelihood strategy. About 1.2 million people living in fishing communities around Tonle Sap depend nearly entirely on fishing as their main occupation, with 10.7 million people in Cambodia dependent to some extent on captured fisheries. Fish is considered as "shared" natural resources, and trans-boundary in nature. Many species of fish require different habitats, which locate in different countries during their life cycle to meet their condition for survival. Fish has important economic and social benefits to the large population of the basin in each country, and thus will occupy an important place in the development of the Mekong. Collaborative management among four countries is of crucial importance to sustain these resources.

2.10.2 Importance of Varied Habitats and Migrations

What makes the Mekong so productive? The productivities and biodiversities are based on the rich and wide ranges of permanent and seasonal habitats, which are results of Mekong complex geological system. Habitat diversity is greatest in the floodplain areas of flooded grasslands, flooded forests as well as small and large river channels and permanent and temporary lakes and pools. Fish and other aquatic animals use this range of habitats for spawning, feeding and coping with seasonal changes in water levels. MRC's Fishery Program clarified the life cycle and habitats of major migratory fished in the Lower Mekong basin as illustrated below.

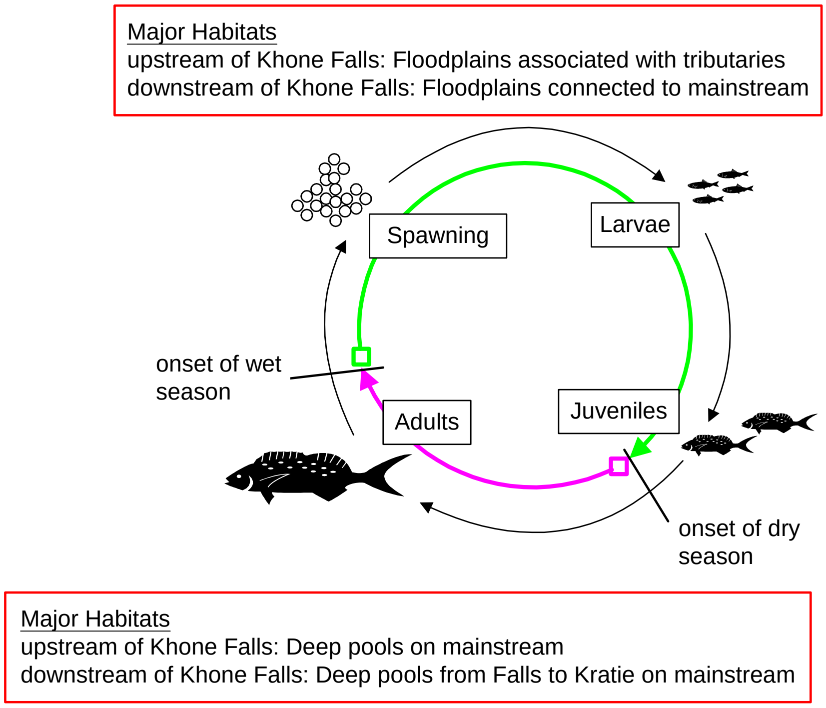


Fig. 2.29 Life Cycle of Major Migratory Fishes
(Source: MRC Fishery Programme)

The large floodplain areas in the Mekong Delta and around the Tonle Sap Lake (the Great Lake) are crucial nursery habitats. Deep pools and channels in the mainstream near Kratie in Cambodia, in the Nam Theun and Nam Hinboun in Lao PDR, and in the Se San River in Cambodia are important dry season refuges for fish, which re-colonize the floodplain when water levels rise with the next rainy season. Many important commercial species swim hundreds of kilometres and across borders from the Mekong Delta, through Cambodia to Thailand or Lao PDR through the Mekong mainstream, to Lao PDR through the Se Kong River, or to the Central Highlands in Vietnam through the Se San and Sre Pok rivers. Also, the larvae (fry) of some species drift hundreds of kilometres from upstream spawning grounds to the floodplains where they feed and grow. Other species migrate laterally over shorter distances to spawn, feed and find refuge.

2.10.3 Hydrological Cycle

Hydrological cycle is the main parameter influencing the river ecology. The annual flood pulse caused by monsoon rain is responsible for flooding the highly productive floodplain. Floodplains are very productive for fish and other aquatic animal in that the flood pulse results in the recycling of plants, animals and nutrients. The flood pulse regime supports higher yield than stable aquatic or terrestrial ecosystem. Seasonal changes in water flow and level causes seasonal changes in aquatic habitats, water quality, flood availability for fish, and fish recruitment.

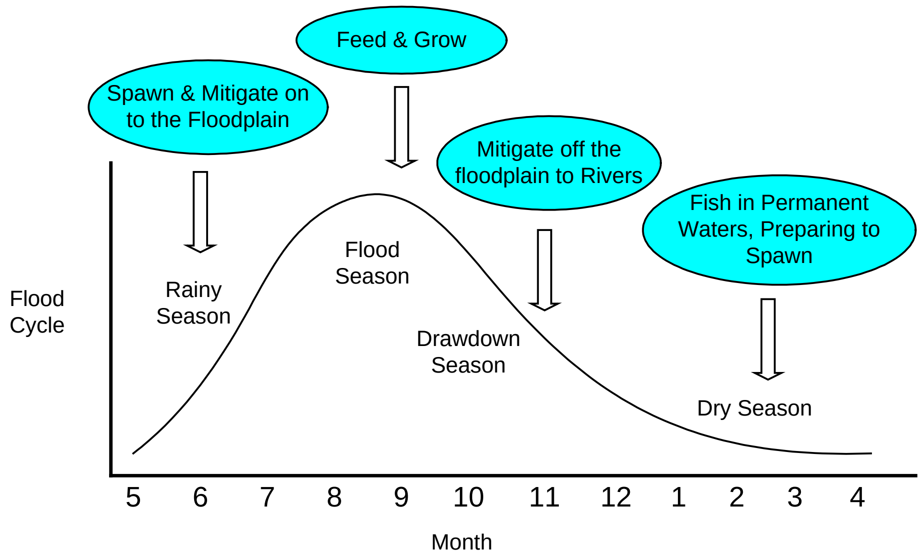


Fig. 2.30 Generalized Cycle of Major Migratory Fishes in relation to Seasonal Conditions (Source: State of the Basin Report 2003, MRC)

The onset of flood trigger many fishes to spawn. Eggs and larvae drift downstream to floodplains with the current, and distribute throughout the floodplains, an optimal rearing condition for the rearing of young and fragile larvae.

2.10.4 Relationship between Fish Catches and Flood Level

Maximum water level together with water level range represents a key factor in floodplain hydrology. MRC studies show that fishery yields are higher in high flood years. In the occurrence of drought year of 1998/99, fish production has dramatically dropped. Figure below shows the relationship between the maximum water level of Tonle Sap Great Lake and the fish catch volume of *dai* fishery (Status of the Cambodian Inland Capture Fisheries Sector with Special Reference to the Tonle Sap Great Lake, Nicolas Van Zaling, Nao Thuok and Sam Nuov, 2001).

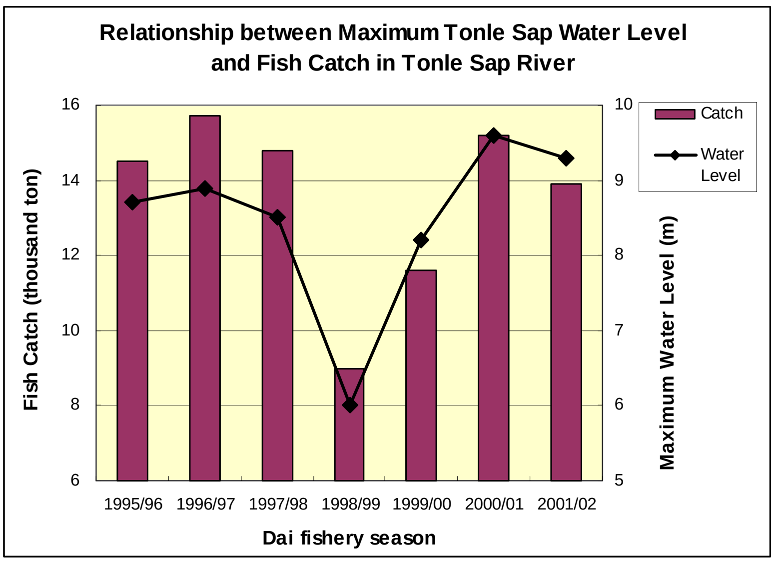


Fig. 2.31 Relationship between Maximum Tonle Sap Lake Water Level and Fish Catch in the Tonle Sap River

Spawning success of fishes is closely related to available spawning grounds. High flood means that fishing activities are dispersed more evenly at wider areas giving better possibilities for young fishes to survive. A *dai* is a kind of bagnet or stationary trawl positioned in the Tonle Sap River to capture migratory fish. It is noted that main species in the *dai*-fishery is *riel (Henicorhynchus siamensis)*, which totals 39% of the catch. This species uses inundated areas for feeding on plant remnants and periphyton; the spawning areas and spawning time is unclear. It is quite obvious that the species benefit so largely on large floods. The dai fishery operates usually from the end of October until around the middle of March. As the floods recede, fish move out of the submerged lands (floodplains) around the Great Lake into the lake itself. They then migrate via the Tonle Sap River to the Mekong mainstream. More than half of the season's catch takes place in January. There is a close relationship between the maximum flood level of the season and the fish catch. The greater the area of floodplain inundation and the longer the duration of flooding, the greater the volume of fish becomes. Every year, the size of the Tonle Sap floodplain varies tremendously from the dry to the wet season. In the dry season, the Great Lake is only around 3,000 km^2, while in the wet season the lake grows to between 10,000 and 15,000 km^2. In the 1998/99 drought, fish production was far less than in normal years, since much less land was inundated. Fish productivity is closely related to the extent of floodplain inundation.

As indicated above, it is likely in the course of IBFM that decision of the environmental flows or finally the quantification of surplus water at key locations will inevitably involve trade-offs between development and environmental preservation (assessment of the economic and social benefits and the environmental and social costs of the alternative development scenarios). Agreement on the trade-offs will require a significant amount of discussion within the riparian countries leading to recommendations being forwarded to the Joint Committee.

2.11 Introduction of Normal Flow Approach in Japan

2.11.1 General

The basic concepts of "Maintenance of Flows on the Mainstream" are similar to those of "Normal Flow" applied in Japan. The normal flow is defined as the river flow that shall be required to maintain the normal functions of river in view of proper river control and management. The normal flow shall be designed to satisfy both needs of the maintenance flow and off-stream water uses as illustrated below. The overall goal is to formulate a sustainable coexistence between human beings and rivers.

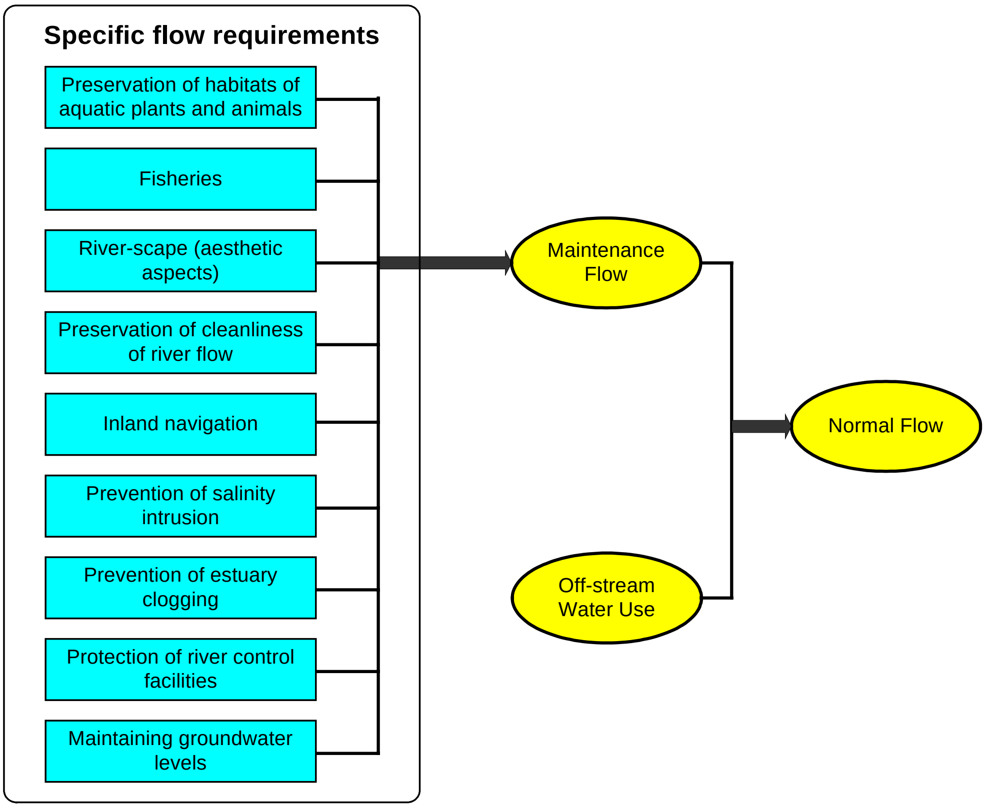


Fig. 2.32 Key Flow Factors and Requirements of Normal Flow in Japan

The maintenance flow shall be determined and maintained even at the time of low flow, upon overall considerations of specific flow requirements; preservation of habitats of aquatic plants and animals, inland navigation, fishery, river scenery, prevention of salinity intrusion, prevention of estuary clogging, protection of river control facilities, maintenance of groundwater levels, as well as preservation of cleanliness of river flow (self-purification of water pollution). The normal flows shall be maintained considering flow fluctuations all year round as well as emergency induced by droughts. Key points for determination of the normal flows are listed below.

(1) Basic data and information needed for determination are river course conditions, natural river environment, social environment, historically severe drought conditions, river flow regimes, river control facilities, water abstractions for various water uses, etc.

(2) The normal flows shall be determined so that the river can fulfill its function at all river stretches. Thus the river course is divided into several stretches in view of environmental characteristics of river. For each river stretch, the maintenance flow shall be determined as a constant (fixed) flow requirement. The in-stream water uses vary by location and by season. In each river stretch, if some specific flow requirement needs to be variable seasonally or monthly, the maintenance flow shall be set up on seasonal or monthly basis.

(3) Off-stream water uses shall be determined on the basis of actual water utilization conditions. Permitted water rights and customary water rights are subject to off-stream water uses.

(4) In view of proper low flow management, one or more representative monitoring points shall be established to monitor the normal flow, where the maintenance flow and off-stream water utilization shall be suitably managed. The normal flow at the selected monitoring points shall be determined based on the water balance between the current flow regime and

the seasonal or monthly requirements of the maintenance flow and off-stream water utilization at all river stretches.

(5) The quantities of existing off-stream uses are registered in the cadastre of the River Administrator. However, the required flow for in-stream uses has not yet been completely established, since the ecological flow requirement is different from river to river and its reasonable and academic estimation is not so easy. The required flow for in-stream uses is still being studied and endeavored, although the draft guideline for its estimation approaches has already been prepared.

2.11.2 Flow Requirements for Fishery Management

Flow requirement from the aspects of "preservation of habitats of aquatic plants and animals" and "fisheries" is determined seasonally giving a priority in freshwater fisheries management. The suitability of flow regimes for the representative fishes selected is taken as the primary factor for seeking for flow requirement. The general process is shown in Fig. 2.31.

2.11.3 Target Maintenance Flows of Major Rivers in Japan

The plots below (Fig. 2.32) show the target maintenance flows in 403 major rivers in Japan for reference. The drainage area covers only from 10 to 10,000 km^2 because of river size in Japan (Guide to Normal Flow Study (Draft), Ministry of Land, Infrastructure and Transport, River Environment Division, River Bureau, July 2001).

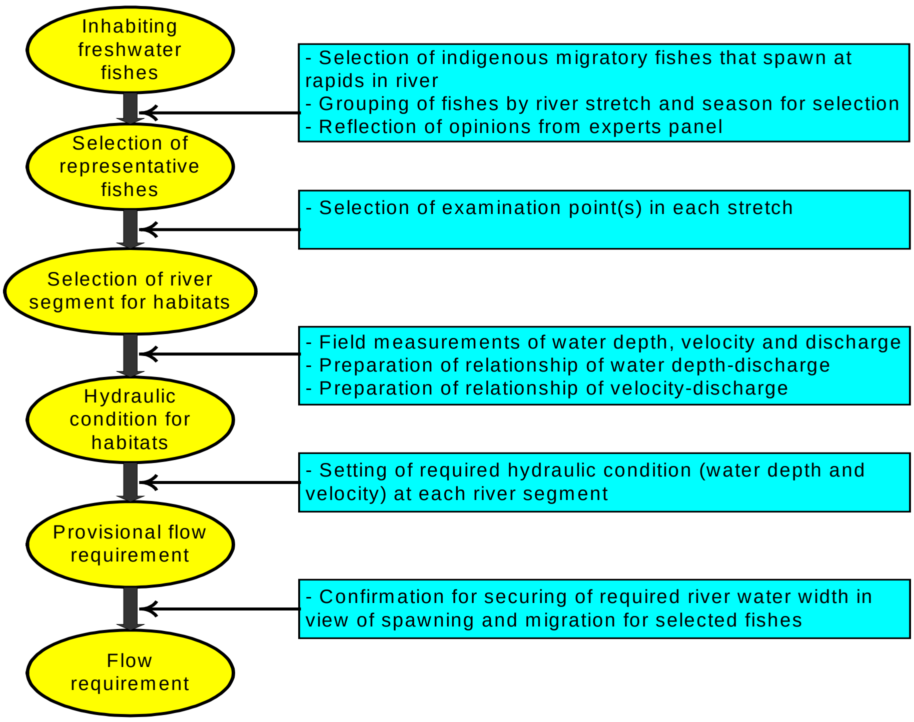


Fig. 2.33 General Process of Flow Requirement for Fishery Management in Japan

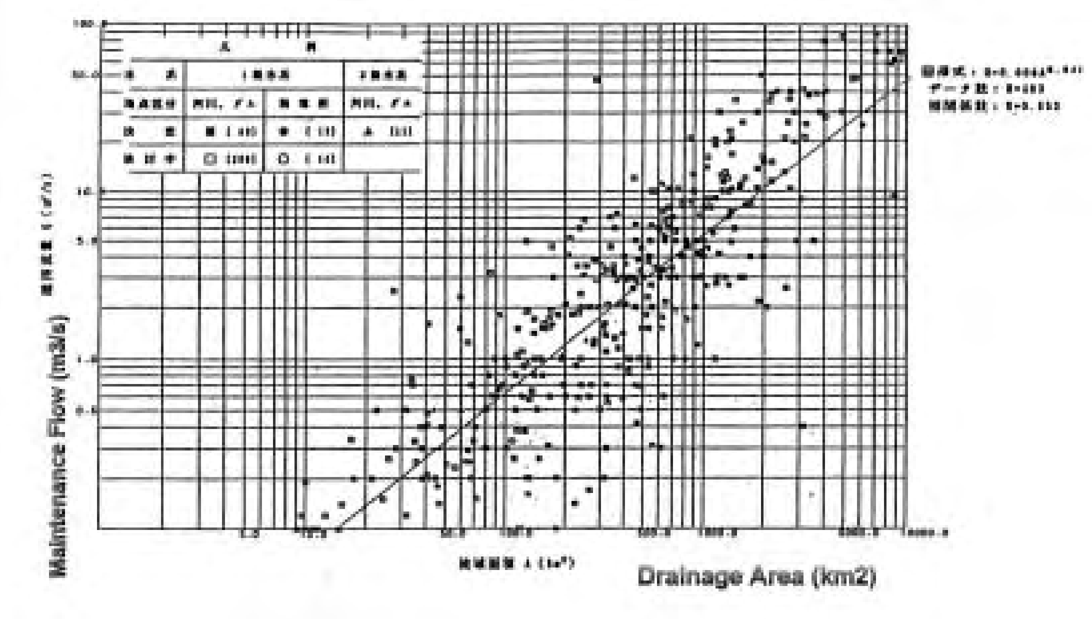


Fig. 2.34 Relationship between Drainage Area and Maintenance Flow for Major Rivers in Japan

As seen above, there is a large scatter in the target maintenance flows between all rivers within Japan. This reflects variability of key flow requirements peculiar to each river but might be to a greater extent indicative. Linear regression is applied for providing general information to rivers where very limited data is available as follows:

$$Qm = 0.008 \times A^{0.941}$$

where, Qm : maintenance flow (m^3/s)

A: drainage area (km^2)

It is of course not considered technically appropriate to apply this relationship in small-size rivers in Japan to the Mekong River of extremely larger size for the estimation of maintenance flow. Nevertheless it is applied for comparison to the mean monthly discharges in the dry season at hydrologic stations on the Mekong mainstream.

Preliminary estimation and comparison are merely made in terms of transposition by the linear regression above and the results are as follows:

Table 2.5 Comparison of Dry Season Monthly Mean Discharges on Mekong Mainstream with Estimated Maintenance Flows Appling Relationship of Rivers in Japan (Reference Only)

Station Name	*Drainage Area (km^2)*	Discharge (m^3/s)		
		Applied	March	April
Chiang Saen	189,000	738	835	915
Luang Prabang	268,000	1,026	1,065	1,112
Chiang Khan	292,000	1,112	1,043	1,056
Vientiane	299,000	1,137	1,167	1,194
Nong Khai	302,000	1,148	1,176	1,215
Nakhon Phanom	373,000	1,400	1,548	1,526
Mukdahan	391,000	1,463	1,600	1,569
Khon Chiam	419,000	1,562	1,903	1,839
Pakse	545,000	2,000	1,852	1,819
Stung Treng	635,000	2,309	2,209	2,114
Kratie	646,000	2,347	2,320	2,275
Kompong Cham	660,000	2,395	2,047	1,849
Chroui Changvar	663,000	2,405	1,964	1,931

Source: WUP-JICA Study Team

The estimated maintenance flows almost exceed the monthly mean discharges in March and April on the Mekong. The relationship between the target specific maintenance flow in terms of per 100 km^2 and drainage area in major Japanese rivers is shown below for reference.

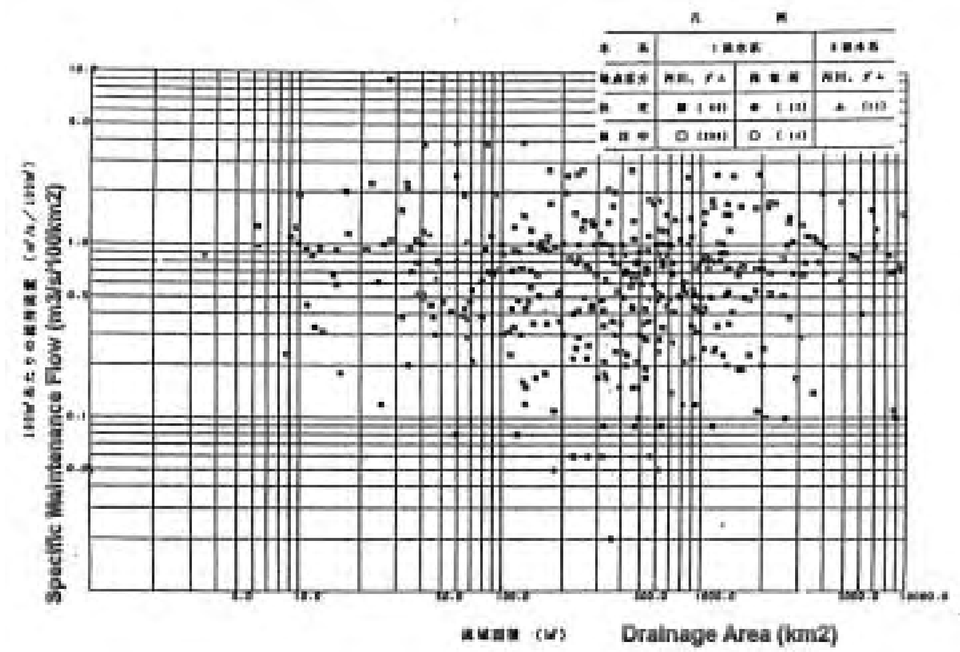


Fig. 2.35 Relationship between Drainage Area and Specific Maintenance Flow for Major Rivers in Japan

The average specific maintenance flow is 0.69 $m^3/s/100km^2$. Although a large scatter is observed in the plots, a majority is plotted in the range 0.3-1.5 $m^3/s/100km^2$. Table below shows the specific discharges in the dry season at hydrologic stations on the Mekong mainstream for comparison.

Table 2.6 Specific Discharges in Dry Season at Hydrologic Stations on Mekong Mainstream

Key Station	March		April	
	Mean (m^3/s)	Specific Discharge ($m^3/s/100km^2$)	Mean (m^3/s)	Specific Discharge ($m^3/s/100km^2$)
Chiang Saen	835	0.44	915	0.48
Luang Prabang	1,065	0.40	1,112	0.42
Chiang Khan	1,043	0.36	1,056	0.36
Vientiane	1,167	0.39	1,194	0.40
Nong Khai	1,176	0.39	1,215	0.41
Nakhon Phanom	1,548	0.42	1,526	0.41
Mukdahan	1,600	0.41	1,569	0.40
Khon Chiam	1,903	0.46	1,839	0.44
Pakse	1,852	0.34	1,819	0.33
Stung Treng	2,209	0.35	2,114	0.33
Kratie	2,320	0.36	2,275	0.35
Kompong Cham	2,047	0.31	1,849	0.28
Chroui Changvar	1,964	0.30	1,931	0.29

Source: WUP-JICA Study Team

It should be noted that:

(1) Tables for comparison above are only for reference purposes. River size, hydrological conditions, water uses, land use and river flow regimes of rivers in Japan are quite different from the Mekong River.

(2) Freshwater fisheries in Japan are not so active compared to those in the Mekong River. Flow requirement for fishery management is focused on the habitat condition of indigenous fishes from hydraulic aspects instead of fishery production. On the contrary, the Mekong River is characterized as much higher of biodiversity in wetlands as well as river channels.

2.11.4 Fulfillment of Normal Discharges

In Japan, the River Administrator must establish the minimum river flow required for the maintenance of desired river functions in each river section according to the River Law. Further, in Japan, river water has been highly used since olden days. Currently there is no available surplus water in rivers when drought occurs. Serious water shortages have been experienced in cases of historically severe drought. Supplemental water cannot be abstracted from rivers without construction of storage dams.

The River Administrator shall be responsible for satisfying the maintenance flow as well as off-stream water uses except for the case of emergency induced by extreme drought. In this connection, design low flow is adopted to satisfy both the maintenance flow and off-stream water uses (totally the normal flow). In Japan, the design low flow is determined as the river flow regime of a 10-year drought probability (that is the flow regime of non-exceedance probability of 10%). As a result, all the river water uses in any category is ensured to the extent of a 10-year drought. This is examined and confirmed by the River Administrator in terms of the water balance between the design flow regime and all the river water uses. The return flows from irrigated paddy fields and supplemental release from existing reservoirs are reflected in this water balance.

3. NATURAL CONDITIONS AND WATER RESOURCES ISSUES IN THE MEKONG DELTA

3.1 General

The basic study on the preliminary analysis of the minimum flow requirement on the Mekong mainstream started in May 2002 in the second phase of the WUP-JICA Study. A specific reference was given to the Mekong Delta as a starting point of the study based on the technical considerations that quantification of the surplus water in the entire Mekong basin (the surplus quantities of water at each station as specified in Article 26) shall be based on the downstream end location of the Mekong River.

The current water use in the Mekong Delta is very active. Major water use in the delta is for irrigation. Key elements of water use as well as the related minimum flow needs are illustrated below.

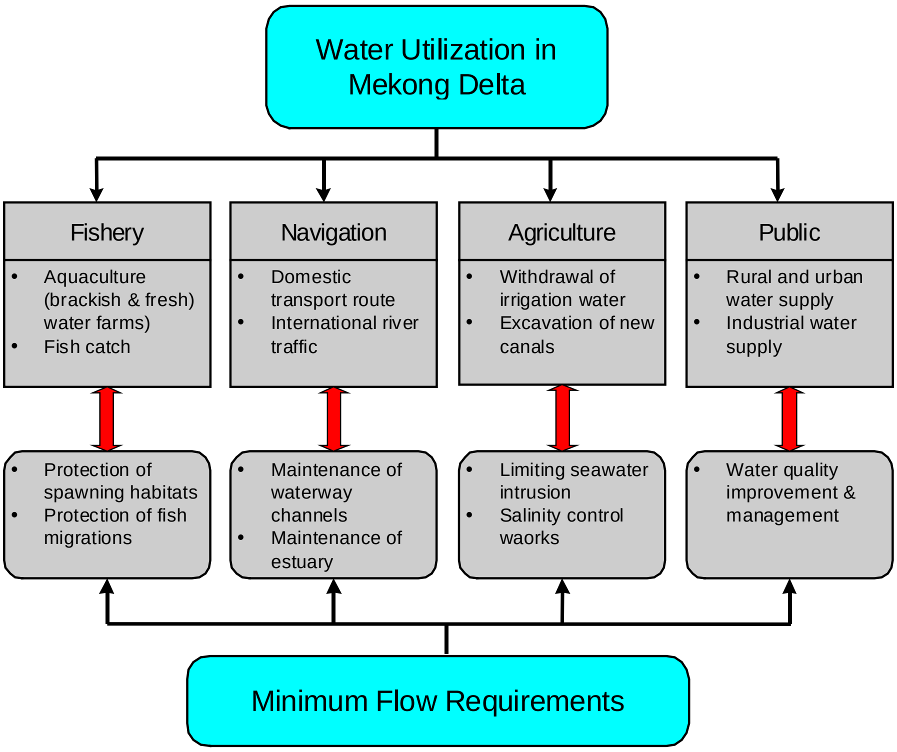


Fig. 3.1 Relationship between Water Use and Minimum Flow Requirements in Mekong Delta

Seawater intrusion is closely related to the current irrigation water use. Seasonal variation of salinity intrusion is a technical factor for determining the minimum flow requirements in the Mekong Delta with respect to providing a necessary flow for limiting seawater intrusion. The current study thus focused on investigations and clarifications on the salinity conditions and hydrological behaviours in the delta. Various kinds of data and information were collected from available reports and line agencies in Vietnam.

3.2 Vital Role of the Mekong Delta in Vietnam Economy

It is generally said that the Mekong Delta covers an area of 45,000 km^2, of which 39,000 km^2 lies within the borders of Vietnam in the majority of 87% of the whole delta. The description of Mekong

Delta hereinafter refers to the delta in Vietnam. The Mekong Delta is 12% of the total land area of Vietnam. About 16 million Vietnamese, or one in every five, live in the delta. The delta covers 4.9% of the entire Mekong River Basin (795,000 km^2), or 6.4% of the Lower Mekong River Basin (606,000 km^2).

The Mekong Delta is where the economy has responded quickly to the government's "open door (doi moi)" reform policy. The economy of the delta is oriented towards the primary sector, and it is the major agricultural production area of Vietnam. It accounts for 27% of the total GDP of Vietnam, some 40% of agricultural production, and half of rice production in the country. Paddy production is at 11 million tons, nearly 740 kg/capita (despite the high population density of nearly 400 persons/km^2), making the Mekong Delta the largest producer compared to other river basins in Vietnam. Rice and fishery products contribute significantly to the nation's export earnings. The delta contributes to the export of rice for approximately 85%.

The lowlands, particularly the areas of recent alluvium, have historically been the most densely populated and productive agricultural part of the lower Mekong basin. Although large tracts of land in the delta, particularly the Plain of Reeds, the Long Xuyen – Hatien quadrangle and the interior of the Ca Mau peninsula, consist of acid-sulphate soils, it is thought that with ample supply of water and proper land water management these soils can be made productive. In general the delta has much potential for water resources development for agriculture. The Mekong Delta covers 12 provinces. The population distribution of the Mekong Delta in 1998 is given in the following table.

Table 3.1 Population and Density of Mekong Delta in 1998

Province	Area (ha)	Population	Density (person/km^2)
Long An	444,885	1,306,202	294
Tien Giang	232,694	1,605,147	699
Ben Tre	228,191	1,296,914	568
Dong Thap	323,530	1,564,977	484
Vinh Long	147,370	1,010,486	686
Tra Vinh	236,694	965,712	408
Can Tho	296,300	1,811,140	611
Soc Trang	320,027	1,173,820	367
An Giang	340,623	2,049,039	602
Kien Giang	625,564	1,494,433	239
Bac Lieu	248,925	736,325	296
Ca Mau	521,511	1,117,829	214
Total	**3,965,314**	**16,132,024**	**407**

Source: MRC and KOICA, Flood Control Planning for Development of the Mekong Delta (Basin-wide), September 2000

3.3 Land Use

In Vietnam, the Mekong Delta supports the growing agricultural production and aquaculture covering around 2.9 million ha (as of 1998) of land. Out of the lands, around 2.2 million ha is irrigated for paddy and triple and double cropping areas are around 1 million ha. Land uses in the delta in 1992 and 1998 are presented below.

Table 3.2 Land Use in the Mekong Delta in 1992

Land Use	Gross area (1,000 ha)	% of delta area (3.9 mill. ha)	% of agricultural area (2.46 mill. ha)
1. Annual crops	**1,969**	**50.6**	**80.0**
- Triple rice crops	75	1.9	3.0
- Triple crops of rice and upland crops	3	0.1	0.1
- Double rice crops	950	24.4	38.6
- Double crops of rice and upland crops	35	0.9	1.4
- Single rice crops	762	19.6	31.0
- Upland crops	144	3.7	5.9
2. Perennial crops	**346**	**8.9**	**14.1**
3.Water surface for agricultural uses	**145**	**3.7**	**5.9**
Sub-total of Agricultural Land	***2,460***	**63.2**	***100***
4. Forest lands	**377**	**9.7**	**-**
5.Other (including waste lands, waterways and unclassified)	**1,057**	**27.1**	**-**
Grand Total of Mekong Delta Area	**3,894**	**100**	**-**

Source: Master Plan for the Mekong Delta in Viet Nam, 1993

Table 3.3 Land Use in the Mekong Delta in 1998

Land Use	Gross area (1,000 ha)	% of delta area (3.97 mill. ha)	% of agricultural area (2.92 mill. ha)
1. Agricultural Land	**2,923**	**73.7**	**100.0**
a. Lands for annual crops	2,232	56.3	76.4
- Double crops of rice and upland crops	2,072	52.3	70.9
- Upland crops	9	0.2	0.3
- Other annual crops	151	3.8	5.2
b. Lands for mixed gardens	151	3.8	5.2
c. Lands for perennial trees	332	8.4	11.4
d. Water surface for aqua-culture	207	5.2	7.1
e. Other agricultural lands	0.1	0.0	0.0
2. Forestry Land	**297**	**7.5**	**-**
3. Lands for Construction	**205**	**5.2**	**-**
4. Lands for Settlement	**103**	**2.6**	**-**
5. Lands not yet used	**227**	**5.7**	-
a. Flat uncultivated lands	131	3.3	-
b. Mountain uncultivated lands	17	0.4	-
c. Water surface not yet used	32	0.8	-
d. Other lands not yet used	48	1.2	-
6. Rivers and Creeks	**210**	**5.3**	**-**
Grand Total of Mekong Delta Area	**3,965**	**100**	**-**

Source: Report name is unknown.

3.4 Agricultural Land Use, Production and Yield

The land use is discussed in the previous section. In this section the current agricultural land use is detailed since another report is available. As of 2001, around 2.6 million ha of the Mekong Delta is used for agricultural purposes. Out of this area 2,439,000 ha (94%) has been cultivated, of which 2,088,000 ha (86 %) is estimated to be for annual croplands and the rest (351,000 ha) is for perennial croplands. The annual croplands consisted of 1,970,000 ha of paddy fields and 308,000 ha of upland fields. Of the paddy fields, 1,478,000 ha or 75% of the paddy fields are irrigated and the remaining are non-irrigated. Furthermore, about 2% (9,000 ha) of the upland crop areas are irrigated. While there are considerable varieties of paddy cropping system in the Mekong Delta, double paddy cropping is the predominant cropping system: winter-spring (post-wet season) paddy (Nov./Dec.-Feb./Mar.) and summer-autumn (pre-wet season) paddy (Apr./May-Jul./Aug.). Paddy cropping systems are depending mainly on climatic and water control conditions. In the central part of the delta where the natural water control conditions are favorable because of easy access the Mekong flow, there is already a considerable area under the three paddy cropping systems. On the other hand, in the deep-flooded or long saline-intruded parts of the delta, single paddy cropping is being done; deepwater rice from July to December and floating rice from May to December. The annual upland fields of 308,000 ha are usually planted with upland crops such as maize, soybean, mungbean, groundnut, sesame, sugarcane, kenaf, and vegetables, etc. Major perennial crops in the basin are coconut and fruit trees including banana, pineapple, longan, mango, dragon fruit, milk fruit, etc.

Fig. 3.3 Irrigation Canals and Salinity Control Structures in Mekong Delta, from MRC Irrigation Database
(Note: Salinity control structure is shown as a point)

The present land use and prevailing cropping pattern in the basin are shown in Fig.3.2. Based on the existing statistical data and other relevant documents, agricultural production and crop yields in 2001 are estimated as shown below. Fig. 3.3 is an example of the MRC irrigation database map showing the current irrigation canals (primary and secondary canal systems) and salinity control structures in the Mekong Delta.

Table 3.4 Agricultural Production and Crop Yield in the Mekong Delta in 2001

Crop	Cultivated Area (ha)	Yield (ton/ha)	Production (ton)
Paddy	**3,382,000**		**14,323,400**
Winter-Spring (irrigated)	1,412,000	5.2	7,342,400
Spring-Autumn (irrigated)	1,378,000	4.0	5,512,000
Spring-Autumn (rainfed)	290,000	2.5	725,000
Rainy (irrigated)	100,000	3.4	340,000
Rainy (rainfed)	202,000	2.0	404,000
Maize	**6,000**		**19,200**
Winter-Spring (irrigated)	500	4.2	2,100
Winter-Spring (rainfed)	2,500	3.0	7,500
Spring-Autumn (irrigated)	500	4.2	2,100
Spring-Autumn (rainfed)	2,500	3.0	7,500
Cassava (rainfed)	**10,000**	**9.0**	**90,000**
Beans	**6,000**		**16,800**
Winter-Spring (irrigated)	1,00	2.4	2,400
Winter-Spring (rainfed)	5,000	1.2	6,000
Spring-Autumn (irrigated)	1,000	2.4	2,400
Spring-Autumn (rainfed)	5,000	1.2	6,000
Sugarcane	**65,000**		**3,585,000**
Irrigated	500	75.0	37,500
Rainfed	64,500	55.0	2,760,000
Coconut	**71,000**	**5.0**	**355,000**
Other annual crops	**66,000**		
Other perennial crops	**92,000**		

Source: JICA (2002), Study on Nationwide Water Resources Development and Management in the Socialist Republic of Vietnam

3.5 Direction of Agricultural Development in the Mekong Delta

Currently, there are 2.6 million ha of land used for agricultural activities. Nearly all planted annual crop areas in the delta grow paddy. The potential for expansion of agricultural land is limited to about 0.2 million ha at present. However, the Mekong Delta has abundant land resources for further expansion of agricultural land on condition of providing proper water control systems. Generally, the soils of the delta pose no major constraint to agriculture, except acid-sulfate soils mainly extended over the Plain of Reeds.

The availability of water resources in the delta alternates every 6 months, from surplus to shortage. In July-December, heavy rainfall and runoff occur over the 6 months, causing long periods of inundation over 25% of the delta due to the flood inflow of Mekong River. The northern delta is inundated as a result of overtopped banks of the river system; and the southern delta is inundated as a result of poor drainage, low-lying lands and depression in the area. Cropping patterns in the delta have been adapted to these natural behaviors over the years. Therefore, it would be said that the delta’s agricultural potential could only be exploited fully if water control measures are taken to deal with the alternating vagaries of water surplus and shortage. The most important water control measures in that respect are irrigation during the dry season and flood control and drainage during the wet season.

Many water control measures have already been implemented in the delta. There is an extensive system of primary and secondary canals and of flood protection embankments. According to the Mekong Delta Master Plan in 1993, actual water control is exercised in the water control units: flood control at the secondary unit level, irrigation and drainage at the tertiary/farm unit level. Irrigation is mostly by low lift pumping from the canal system. The water control infrastructure is more complete in the central part of the delta than in the outer areas. In order to increase the cropped area and cropping intensity in the delta, it will be absolutely necessary for strengthening water control measures under a long-term water control program.

The main thrust of water control measures, particularly related to irrigation would be: (a) on-farm development; and (b) canal improvement (enlargement of existing and construction of new, primary and secondary canals and water control structures, such as salinity control sluice gates) to bring more irrigation water to the already irrigated areas, as well as to improve drainage conditions and promote flushing of acid water. The basic development direction in the Mekong delta stipulated in the Strategy for Agricultural and Rural Development for 2001-2010 is as summarized below.

Direction for agricultural development is to focus on promoting an integrated agriculture, diversifying production and pushing up local advantages, such as food production, foodstuff, animal husbandry, fruit tree, aqua-culture and catching.

(1) **Food production:** Food production will be developed at a certain level with an area of 3,898,800 ha. Rice cultivation by 2010 will be allocated with 1,930,000 ha and annual rice export of 4 million tons. Besides, maize will also be developed by 2010 with an area of 100,000 ha and productivity of 549,000 tons.

(2) **Sugarcane:** Keep area for sugarcane plantation stabilized for providing materials for 8 sugar plants in the basin. By 2010, there 80,000 ha of sugarcane will be intensified for meeting productivity of 5.6 million tons of sugar.

(3) **Fruit tree plantation:** Improve mixed garden, intensify and expand area for obtaining 279,200 ha of tropical fruits such as banana, pineapple, longan, mango, dragon fruit, milk fruit, etc. for meeting with domestic and export requirement. Pineapple (40,000 ha), banana (40,000 ha), mango (60,000 ha), longan and litch (25,000 ha), etc., will be allocated along Tien and Hau rivers, Ca Mau, West Hau River, and North Tien Giang.

(4) **Animal husbandry:** Focus in developing 2 livestock of pig and poultry. By 2010, cowherd is expected to reach 3.7 million by intensifying, to meet with local consumption and export. Chicken herd consists of 29.3 million, meat productivity and egg are 52.7 million tons and 770 million, respectively. Duck herd is 24.1 million, 54,200 tons of meet and 825 million eggs, besides egg and feather are to be exported.

(5) **Fishery:** By 2010, total fishery production will be 1.9 million tons, of which aqua-culture and fish catch occupy 912,000 tons and 1 million tons, respectively. With regard to area for aquaculture, it will be 544,000 ha, consisting of 250,000 ha, 32,000 ha and 220,000 ha of tiger prawn, blue legged prawn and caged fish, respectively.

3.6 Aquaculture in the Mekong Delta

Vietnam has the largest aquaculture area in the Lower Mekong Basin, covering 330,000 ha as of 2001. Freshwater aquaculture production in the delta in 1999 was 171,570 tons. Production is high, with a mean annual pond production of 4.8 tons per ha. Eighty thousand is presently under rice-fish culture. The mean annual production is 0.37 tons per ha. Fish are often held in the rice fields for two or three successive rice crops. There are nearly 5,000 fish cages in the waters of the Mekong Delta, ranging from 50 to 400 m^2 in size. Cages are most often stocked with wild captured fry or juveniles. Fish are fed wet sticky balls of mixed rice bran, broken rice, trash fish and vegetables. Fish are cultured for 10 to 14 months and yields range from 80 to 120 kg/m^3. Cage culture of high value species requires levels beyond the reach of poor and marginal farmers.

3.7 Acidification in the Mekong Delta

In the Mekong Delta, the acid-sulfate soils take around 1,600,000 ha or 41% of the delta. The heavy acid-sulfate soil mainly locates in the Plain of Reeds and Long Xuyen Quadrangle, while the moderate acid-sulfate soils that become saline in the dry season locates in the Ca Mau Peninsula. During the dry season, these soils dry out and crack forms, which give way for oxygen penetration to the deeper layers. Consequently, oxidation of pyrite will occur leading to acidification. Acidification products then will be washed or reached into the canal system and finally, the river in the wet season. The water impacted by the products of acidification process will have high concentrations of Al, Fe and SO_4 and the pH value of 3 or lower, whicht are quite toxic for aquatic life and human beings using this water. Fig. 3.4 presents the acidification areas in the Mekong Delta.

3.8 Morphological Features of the Mekong Delta

In the Mekong delta, the Mekong River has a length of 217 km with a drainage area of some 40,000 km^2. The Tonle Sap River joins the Mekong River at Phnom Penh. At this confluence (also known as Chak Tomuk), the Mekong splits into two rivers that continue to the delta, the Mekong River that runs to the south-east direction and the Bassac River, to the south direction. At this point, around 80% of the dry season flow continues down the Mekong, with only 20% flowing to the Bassac. At this point also, it is said that around 95% of the low flow goes down the Mekong, with only 5% flowing into the Bassac. After the Mekong crosses the Vietnam border, it flows about 50 km before the Vam Nao River transfers about 40% of the flow in the Mekong to the Bassac in the dry season. Below the Vam Nao, the flow in the Bassac is approximately equal to the flow in the Mekong River (discussed in detail in Section 4.2). At the lower part of the delta, the Mekong and Bassac rivers bifurcate into main eight branches as schematically shown below.

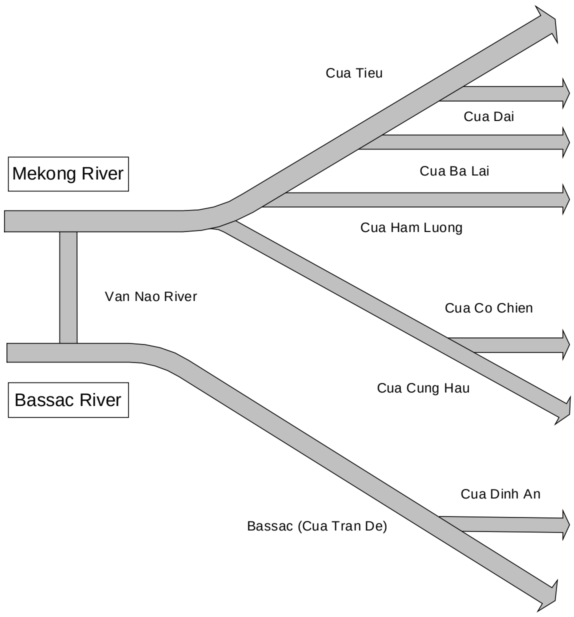


Fig. 3.5 Schematic Diagram of Eight Branches of the Mekong Delta

Downstream of Vinh Long, the Mekong River is divided into five major estuary rivers, the Co Chien, Ham Luong, Ba Lai, Cua Dai and Cua Tieu rivers. The Co Chien River splits into two rivers, the Co Chien and Cung Hau rivers. The Bassac River is rather straight and only divided into two estuary rivers, the Dinh An and Tran De Rivers before flowing into the sea.

In the delta, there is a very dense canal network with a total length of some thousand kilometres. From the hydraulic point of view, these canals linking with the main estuary rivers create a complicated system. The Van Co River is not considered as a Mekong tributary, but in relation to the fresh water supply, flushing of acid water and drainage of flooding water, it has a close hydraulic relationship with the Mekong River. Some major features of delta segment are shown below.

Table 3.5 Major Morphological Features of the Mekong Delta

Segment	Distance from mouth (km)	River	Width (m)	Cross-section (m^2)	Depth (m)			Hydraulic Radius (m)
					Average	Max.	Min.	
Mouth	0-60	Mekong	853	5,795	-10.0	-16.3	-7.4	6.87
		Bassac	1,860	17,870	-12.5	-16.0	-8.4	9.84
Middle	60-140	Mekong	882	6,722	-17.3	-35.3	-6.5	8.45
		Bassac	962	10,552	-16.6	-28.7	-9.6	11.2
Upstream	140-220	Mekong	853	8,207	-15.5	-45.1	-9.0	10.3
		Bassac	647	5,733	-13.6	-40.8	-5.1	9.17
-	-	Ba Lai	312	1,345	-5.64	-	-	3.69
-	-	Ham Luong	1,129	7,335	-9.83	-	-	6.29
-	-	Co Chien	1,053	8,019	-12.2	-	-	7.97

Source: Effect of Configuration Changes on Flow Distribution and Salt Water Intrusion, Program of Salinity Intrusion Studies in The Mekong Delta Phase III, SIWRPM, 1992

Several figures below are the variation of cross section areas and thalweg profiles of Mekong River as well as the Bassac River (Effect of Configuration Changes on Flow Distribution and Salt Water Intrusion, Program of Salinity Intrusion Studies in The Mekong Delta Phase III, SIWRPM, 1992).

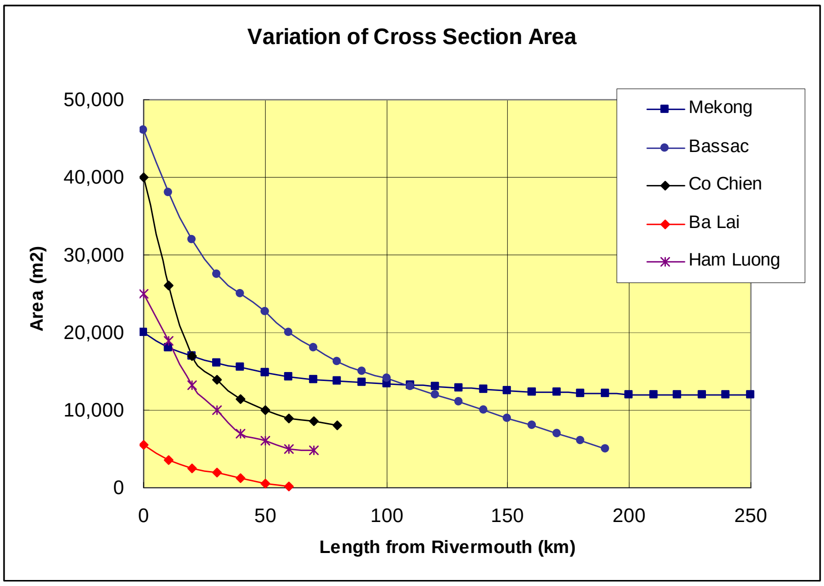


Fig. 3.6 Variation of Cross Section Area of Mekong Branches

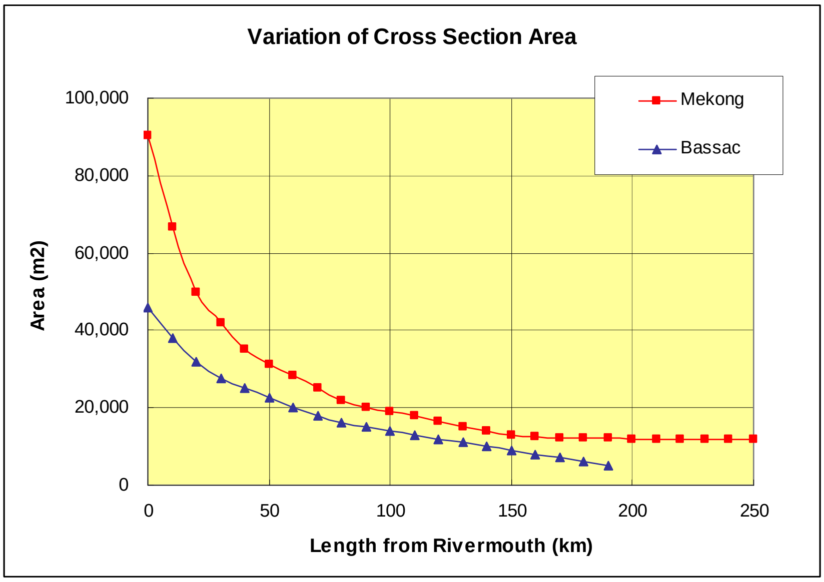


Fig. 3.7 Comparison of Cross Section Area of Mekong and Bassac Rivers

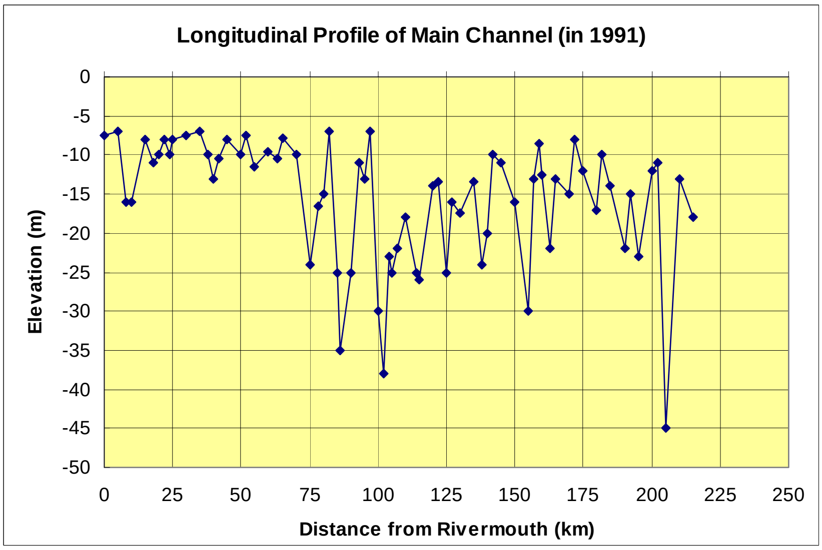


Fig. 3.8 Longitudinal Profile of Main Channel in Mekong River (Cua Tieu Branch)

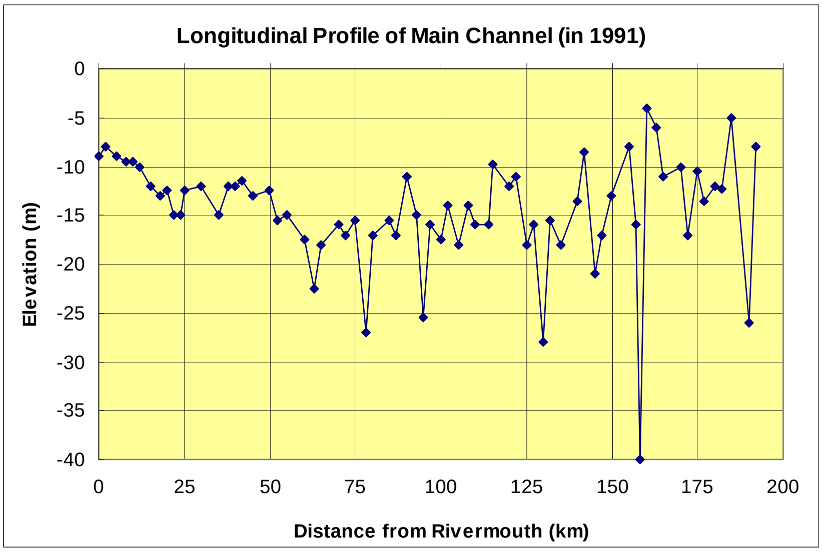


Fig. 3.9 Longitudinal Profile of Main Channel of the Bassac River

3.9 Tides

3.9.1 Major Characteristics of Tides

Tides in the South China Sea are predominantly semi-diurnal with amplitude of some 2.50 to 3.00 m. Tidal effects in the South China Sea propagate up the various tributaries of the Mekong and affect water levels throughout the Mekong Delta and up into Phnom Penh (approx. 330 km from the sea). During the dry season, flow reversal occurs at Tan Chau and Chau Doc. It is said that the tidal amplitude of 0.30 m is observed in the dry season at Phnom Penh.

The table below shows the comparison of tidal characteristics of both the South China Sea and the Gulf of Thailand.

Table 3.6 Characteristics of the South China Sea and Gulf of Thailand

	South China Sea (at My Thuan)	Gulf of Thailand (at Rach Gia)
Tidal Amplitude	3.0 m	0.7 m
Salinity	33 ppt	25 ppt
Highest Tide Level	+1.6 m	+0.5 m

Source: Mekong Delta Water Resources Development Project, Feasibility Study Update, Environmental Impact Assessment and Environmental Action Plan, Annex 1, August 1998

As seen in the table above the South China Sea and the Gulf of Thailand are extremely different, with the tidal amplitude and highest tide level being substantially higher in the South China Sea than in the Gulf of Thailand. In addition, the South China Sea is somewhat more saline than the Gulf of Thailand. The tidal amplitude varies during the spring tide and neap tide cycle. The following information on major characteristics of tides is based on extracts from the Water Level Analysis, Program of Salinity Intrusion Studies in The Mekong Delta Phase III, 1992.

Tide in East Sea (South China Sea): The coast from Vung Tau to Ca Mau Cape is mostly affected by the mixed semi-diurnal tide from the East Sea. Everyday, there are two high water levels (HWL) and two low water levels (LWL). Differences between the two HWLs and the two LWLs are from 0 to 30 cm and from 100 to 210 cm, respectively. The tidal amplitude is up to 3 m at the Mekong river mouths. In every month, there are two periods of spring tides and two periods of neap tides that alternate with each other. During the year, minimum and maximum values of daily highest high water (HHW) are observed in June-July and November-December, respectively. However, both minimum and maximum values of daily lowest water (LLW) are found twice in a year: minimum in June-July and December-January, and maximum in March-April and September-October. Lowest and highest daily mean water level (MWL) take place in June-July and November-December, respectively.

Tide in West Sea (Gulf of Thailand): The coast from Ca Mau to Ha Tien is affected by a mixed tide with dominant diurnal component from the West Sea. The tidal amplitude is from 0.8 to 1.2 m. Differences between HWLs and LWLs are from 30 to 50 cm and from 0 to 30 cm, respectively. During the year, the minimum value of daily mean water level is recorded in April-May, while the maximum values, in July-August and November-December. The difference between the two values is about 20 cm.

Table 3.7 Monthly Mean Sea Water Levels in the Mekong Delta

(Unit: cm)

Station	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Tan An (East Sea)	40	31	24	14	5	-7	-6	1	22	52	61	50
Rach Gia (West Sea)	13	6	5	1	-1	5	8	16	18	27	26	18

Note: Observation period is unknown.
Source: Flood Control Planning for the Inundation Area of the Mekong Delta in Vietnam, SIWRP, 1998

3.9.2 Tidal Amplitude

The table below shows the monthly maximum tidal amplitude at major stations in the delta.

Table 3.8 Monthly Maximum Tidal Amplitude in the Mekong Delta in 1985

(Unit: cm)

Station	River	Month											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Vung Tau	East Sea	351	359	322	341	341	373	368	348	320	346	371	374
Vam Kenh	Tieu	332	315	299	271	323	326	332	310	307	317	336	347
Binh Dai	Dai	305	301	278	286	305	305	298	293	284	297	313	315
Tan Thuy	Ham Luong	308	311	285	294	315	315	304	299	291	308	318	324
Ben Tray	Co Cien	329	332	294	310	335	340	334	331	312	330	343	353
Ganh Hao	Ganh Hao	342	356	322	360	358	350	338	338	334	356	366	368
Rach Gia	West Sea	109	109	110	111	111	123	119	121	94	82	104	110
Tan Chau	Mekong	65	85	95	110	98	96	27	26	9	6	16	33
Cho Moi	Mekong	110	124	130	145	140	139	80	78	35	17	45	72
My Thuan	Mekong	177	187	187	195	193	209	180	186	167	126	131	157
My Tho	Mekong	258	263	257	256	272	279	269	267	249	244	245	248
Chau Doc	Bassac	79	98	108	124	126	107	33	30	10	6	16	38
Long Xuyen	Bassac	134	147	144	154	155	163	112	109	66	40	62	94
Can Tho	Bassac	208	224	215	232	234	247	210	210	168	140	152	184
Dai Ngai	Bassac	303	321	300	312	322	324	299	292	269	274	281	294

Source: Water Level Analysis, Program of Salinity Intrusion Studies in The Mekong Delta Phase III, SIWRPM, 1992

In general, tidal amplitude gradually decreases from downstream to upstream. At Chau Doc and Tan Chau, the maximum amplitudes at 200-220 km from the sea in the dry season are 1.1 to 1.3 m. In the rainy season, they decrease less than 0.1 m. The tidal amplitude reaches the peak at Dai Ngai

(Km 43), and then gradually decreases upstream as a common phenomena. This can be explained by the special characteristics of tidal propagation and the variation of configuration along the Bassac (Hau) River.

3.9.3 Tidal Propagation

Along the Bassac River, the velocity of tidal propagation is almost constant at 23 km/h on average. It takes about 7.5 hours for propagating from Vung Tau to Chau Doc. Along the Mekong (Tien) River, the tidal propagation velocity is around 29 km/h, i.e., from Vung Tau (East sea) and Tan Chau it takes about 7 hours and 45 minutes.

Table 3.9 Velocity of Tidal Propagation in Dry Season (Mekong River)

River Stretch	Vung Tau to My Tho (km 56)	My Tho to Tan Chau (km 220)
Time (hours. minutes)	1.45	6.00
Velocity (km/h)	29	29

Source: Water Level Analysis, Program of Salinity Intrusion Studies in The Mekong Delta Phase III, SIWRPM, 1992

Table 3.10 Velocity of Tidal Propagation in Dry Season (Bassac River)

River Stretch	Vung Tau to Dai Ngai (km 43)	Dai Ngai to Can Tho (km 88)	Can Tho to Chau Doc (km 192)
Time (hours. minutes)	1.30	2.00	4.00
Velocity (km/h)	23.5	22	23

Source: Water Level Analysis, Program of Salinity Intrusion Studies in The Mekong Delta Phase III, SIWRPM, 1992

In small rivers and main canals in the delta, the tidal propagation is highly affected by the topographic conditions, and many tidal interfaces (usually called zones of standing water) are found in the river and canal network. The river flow from the mainstream inland is limited due to these interfaces. Especially, in the Ca Mau peninsula, tide is the major factor determining the water level variation. The tide from the East Sea propagates through rivers such as the My Thanh, Ganh Hao and the canals linked to the Bassac River. The tide from the West Sea propagates through the large rivers such as the Ong Doc, Bay Hap, Cai Lon, Cai Be, etc. At the beginning of the rainy season, water level in the canals rises and salinity decreases mainly due to the effect of rainwater. At the mouths of the main rivers, salinity is lower due to the increase of upstream flow and the local runoff (commonly called freshwater discharge). These characteristics are very important for the studies on salinity intrusion in the Mekong Delta. Attenuation of tidal propagation in the Mekong Delta is available in the Guidelines on the Study Sea water Intrusion into Rivers, H. van der Tuin (1991), as schematically shown below.

Fig. 3.10 Attenuation of Tidal Propagation in the Mekong Delta

In the figure above, the contour means an equal tidal magnitude in cm.

3.9.4 Average Water Levels in the Mekong Delta

Flow regimes in the Mekong Delta are strongly affected by tidal regime. Water levels throughout the Mekong Delta are affected by tides of the South China Sea. The table below shows the average monthly water level at major hydrologic stations in the delta (observation period of each station is unknown).

Table 3.11 Mean Water Levels in the Mekong Delta

(Unit: dm)

Station	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Chau Doc	11.0	7.7	5.9	4.6	4.6	8.0	13.6	21.1	30.4	33.1	26.9	17.0
Rach Gia	1.3	0.6	0.5	0.1	-0.1	0.5	0.8	1.6	1.8	2.7	2.6	1.8
Long Xuyen	8.7	6.4	5.1	3.7	3.5	5.3	8.4	12.4	16.5	18.8	16.9	11.9
Can Tho	6.3	4.6	3.7	2.5	2.0	2.3	4.2	5.9	8.3	10.1	9.9	8.0
Tan Chau	13.5	9.6	7.4	6.0	6.4	11.3	19.0	29.5	37.5	38.3	30.6	20.4
Cho Moi	10.1	7.5	5.7	4.3	4.2	6.9	11.1	17.3	22.9	24.5	20.8	14.7
Cao Lanh	8.5	6.4	4.9	3.5	3.0	4.0	7.3	10.5	15.2	17.1	15.0	11.2
Moc Hoa	7.2	6.0	5.1	4.2	3.7	3.3	3.7	5.0	10.8	16.3	15.7	10.5
Tan An	4.0	3.1	2.4	1.4	0.5	-0.7	-0.6	0.1	2.2	5.2	6.1	5.0
My Tho	4.4	3.5	2.8	1.5	0.5	-0.6	0.0	0.8	2.5	4.7	5.6	4.0

Note: Observation period is unknown.

Source: Flood Control Planning for the Inundation Area of the Mekong Delta in Vietnam, SIWRP, 1998

Two figures below are the comparison of various water level profiles in the Mekong and Bassac rivers. Both observations were made both in April (low discharge in the dry season) and October (high discharge in the wet season) in 1986.

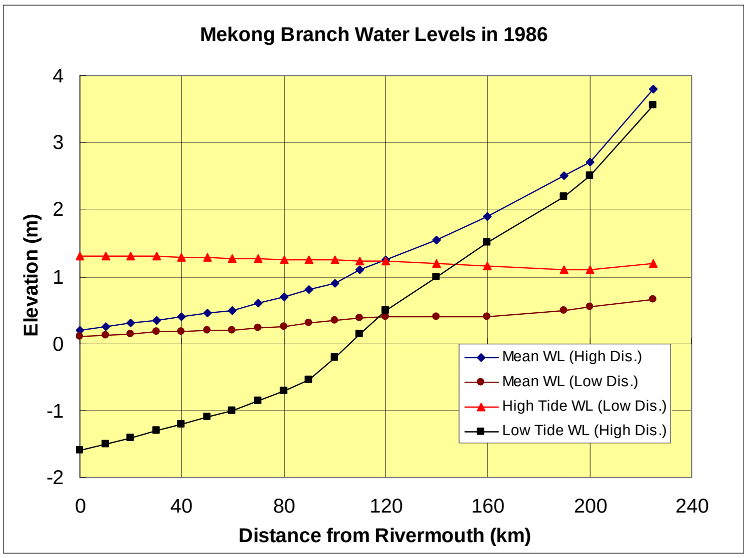


Fig. 3.11 Comparison of Water Level Profiles of the Mekong River in Wet and Dry Seasons

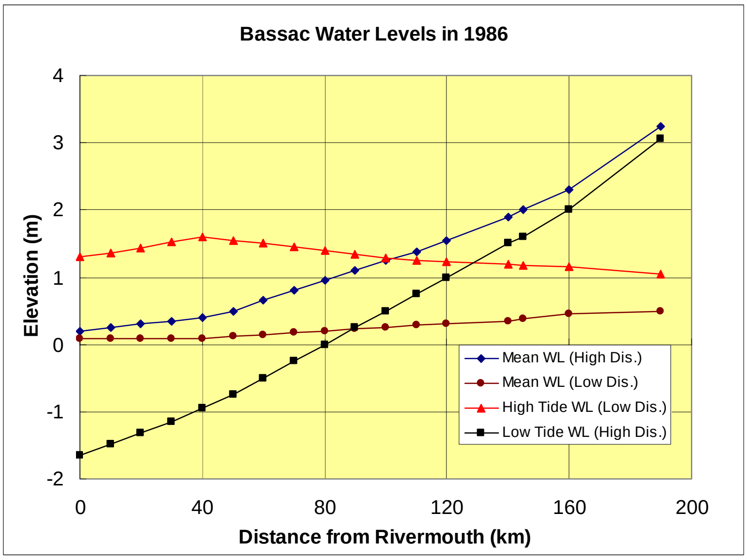


Fig. 3.12 Comparison of Water Level Profiles of the Bassac River in Wet and Dry Seasons

3.9.5 Tidal Effects on the Mekong Mainstream

Tidal effects of the South China Sea propagate to the upstream reaches of the Mekong mainstream. Water levels in Phnom Penh, Cambodia are affected. Fig. 2.12 presents the comparison of hourly water levels in the wet and dry seasons at the Chrui Changvar station located on the Mekong mainstream in Phnom Penh (see location map in Fig. 5.1).

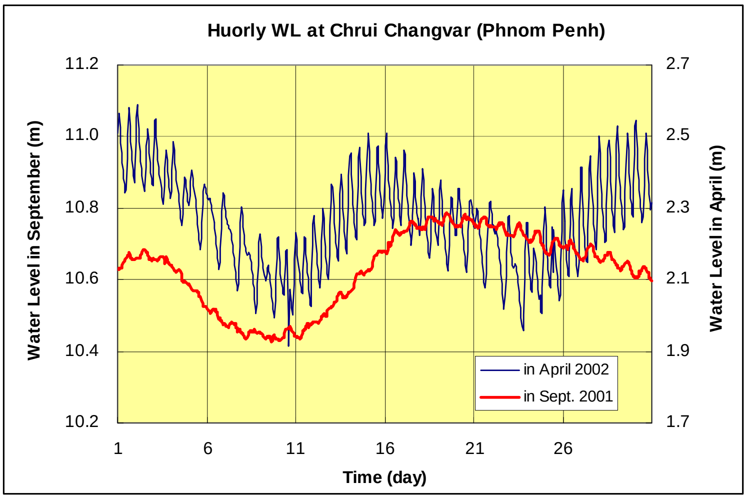


Fig. 3.13 Comparison of Variation Ranges of Hourly Water Levels in Wet and Dry Seasons at Chrui Changvar (Phnom Penh)

As seen above, the tidal range in the dry season (in April when the water level becomes lowest in the year) shows around 20-30 cm, although it comes within 5 cm in the wet season (in September when the water level usually becomes highest). The tidal impacts on water levels are more prominent during the dry season when the Mekong river discharge significantly decreases.

3.10 Existing Water Usage in the Mekong Delta

3.10.1 Domestic Water Use

According to the Mekong Delta Master Plan in 1993, total abstractions for urban and domestic water supply in the delta in 1990 were 52 million m^3, of which approximately 30% were from groundwater. All of the 33 million m^3 of rural domestic water supply and the 12 million m^3 of industrial water supply were supplied from groundwater. The total domestic water supply is less than 1% of the estimated agricultural water supply. Groundwater abstractions for urban and rural domestic water supply were projected to double by 2000. Total projected domestic demand for the delta in 2000 was estimated at 400 million m^3, and total industrial demand for 2000 was estimated at 230 million m^3. These figures are over six times the 1990 supply figures. Projections for 2015 are approximately double those for 2000.

Table 3.12 Water Abstractions for Domestic Water Supply in the Mekong Delta in 1990

(Unit: m^3/day)

Purpose	Surface Water	Groundwater
Urban	101,000 (1.2)	41,000 (0.5)
Rural	0	90,000 (1.0)
Industrial	0	34,000 (0.4)
Total	**101,000 (1.2)**	**165,000 (1.9)**

Note: Figures in a parenthesis are m^3/s.
Source: Mekong Delta Master Plan, 1993

Table 3.13 Projected Domestic Water Demand in 2000 and 2015for the Entire Mekong Delta

(Unit: m^3/day)

Year	Domestic	Other	Total
2000	1,087,000 (12.6)	630,400 (7.3)	1,717,400 (19.9)
2015	2,238,700 (25.9)	1,202,000 (13.9)	3,441,200 (39.8)

Note: Base year for projection is 1990. Figures in a parenthesis are in m^3/s.
Source: Mekong Delta Master Plan, 1993

3.10.2 Irrigation Water Use

The present irrigation water demand in the delta has been estimated on a yearly basis by SIWRP (Sub-Institute for Water Resources Planning) in Ho Chi Minh City by use of the developed hydraulic simulation model in which the current irrigation system network is built. The estimated water demand is on a 10-day basis. Water demands estimated in several years are available from several reports. The table below is the estimated dry season irrigation water demands in 1990, 1998 and 2000.

Table 3.14 Estimated Dry Season Irrigation Water Demands of the Mekong Delta in 1990, 1998 and 2000

Unit	Irrigation Water Demand						Total
	Jan	Feb	Mar	Apr	May	Jun	
million m^3	2,420	1,560	1,120	1,490	1,660	1,140	9,300
m^3/s	904	645	418	575	620	440	-

Source: Sub-Institute of Water Resources Planning and Management (SIWRPM) 199?

1998	Irrigation Water Demand						Total
	Jan	Feb	Mar	Apr	May	Jun	
million m^3	2,686	2,088	2,017	2,179	2,179	1,363	12,512
m^3/s	1,003	863	753	841	814	526	-

Source: Sub-Institute for Water Resources Planning (SIWRP)

2000	Irrigation Water Demand						Total
	Jan	Feb	Mar	Apr	May	Jun	
million m^3	2,582	2,692	2,072	1,400	1,473	1,290	11,509
m^3/s	964	1,113	774	540	550	498	-

Source: Sub-Institute for Water Resources Planning (SIWRP)

The estimated total dry season irrigation demands from January to June are 9,300 million m^3 in 1990, 12, 512 million m^3 in 1998 and 11,509 million m^3 in 2000. Other estimates are available. The dry season demand in 1990 is divided into two demands in the freshwater area and the saline water area affected by saline water intrusion. They are 9,000 million m^3 in the freshwater area and 300 million m^3 in the saline water area. Considering that the Mekong flow becomes lowest in April, period of critical water usage is April. Table below shows the estimated irrigation water usage for 1985 and 1990 over the period January to June by the Mekong Delta Master Plan in 1991. The delta was divided into eight separate climatic zones. Effective rainfall was estimated on the basis of a 75% likelihood of exceedance. An irrigation efficiency of 80% was adopted.

Table 3.15 Estimated Dry Season Irrigation Water Demands of the Mekong Delta in 1985 and 1990

Year	Irrigation Water Demand (m3/sec)					
	Jan	Feb	Mar	Apr	May	Jun
1985	425	310	120	140	275	190
1990	802	724	264	319	214	194

Source: Government of Vietnam, WB and UNDP (1991), Mekong Delta Master Plan, Working Paper No.3, Irrigation, Drainage and Flood Control

3.10.3 Navigation

Navigation is essential to the movement of people and cargoes throughout the Mekong Delta. Within the delta, waterways are the primary mode of transport for goods and people. The Mekong Delta comprises a dense network of rivers, creeks and man-made canals, with a navigable length of more than 4,700 km. The road coverage in the delta is very sparse, given the swampy character of the terrain and the difficulties this poses for road construction. It is estimated that some 70 percent of the total annual cargo moved in the delta (7-8 million tones per annum) is transported by inland waterways and the remaining 30 percent by road.

Cargo traffic has been growing at 10-15 % pa over the 10 years. Cargo traffic is concentrated along two main corridors: Ho Chi Minh City to Ca Mao and Ho Chi Minh City to Kien Luong in Kien Giang Province. In 1991, these two routes accounted for 70-80% of total cargo traffic in the delta. Sea-going vessels transport less than 10% of the cargo. Most cargo is transported through internal waterways and canals. The main ports on the Mekong River are My Thuen, Vinh Thai, Cao Lanh Port and Cao Lanh Silo (rice port). The main ports on the Bassac River are Can Tho, Tra Loc Rice Terminal, My Tho and Ben My Rice Terminal. Can Pho Port, which is of an international port, can accommodate vessels of up to 5,000 DWT capacities. However, the available depth at the mouth of the Dinh An River, which can fall to 2 m at low tide, can only admit sea-going vessels loaded to 3,000 DWT. Can Tho Port operates at only about 50-60% of its capacity because of poor accessibility and the lack of an adequate freight forwarding system. Provincial ports are generally utilised far below capacity because of poor accessibility, poor freight forwarding services and the absence of customs officers.

As far as internal navigation is concerned, there are three main waterways in the Mekong Delta:

(1) Ho Chi Minh City - Cho GAO Canal - Mekong River - Lap VO Canal - Bassac River - CAI San Canal- Reach Gia Ha Tien Canal

(2) East Vam Co River - Thu Thua Canal - West Vam Co River- Dong Tien Language canal - Doc Vang ha Canal - Mekong River - Vam Nao River - Ba The/Mac Can Dung/Tam Ngain Canals

(3) Ho Chi Minh City - Cho Gao Canal - Mekong river - Mang Thit Rivers - Xa No/Chac Bang Cannals

The navigability of the main inland waterways is generally poor because of limited available depth and navigation aids. Only small vessels can unintentionally ply the water of the delta and then only during daylight hours. Larger vessels and barge convoys are forced to sail with the tide. The main problems related to the use of waterways for navigation include:

(1) High velocities in some upstream delta areas at high water

(2) Siltation in estuary reaches and channels and port facilities

(3) Conflicts of interest with other water users, and

(4) Limited maintenance of channels and port facilities

The 1998 Agreement on Waterway Transportation entered into by Cambodia and Vietnam specifies new regulations for the movement of goods and passengers along the maritime and inland waterways of the Mekong River between the two contiguous riparian countries. It is important to note that the Agreement calls for the formulation of specific rules and regulations for navigation and transit traffic, and requires that neither partly will adopt measures, regulations or place obstructions that will directly or indirectly impair the navigability of the mainstream of the Mekong River. These regulations will have to be taken into account in the strategic planning and utilization of water entering the delta through the Mekong and Bassac Rivers.

3.10.4 Fisheries

Fish plays a central role in the human nutrition pattern in the Mekong delta. It is the primary source of animal protein and the source of some indispensable amino acids. The average yearly consumption of fresh fishery products in 1991 amounted to 21 kg/capita. The Mekong Delta has the largest aquaculture area (330,000 ha) and freshwater production is above 170,000 tons. An estimated 80,000 ha are presently under rice-fish culture, with a mean annual production of 370 kg/ha.

Table 3.16 Fisheries Production in the Mekong Delta in 1991

(Unit: 1,000 ton)

Source	Capture	Culture
Rivers and waterways (including cage culture, subsistence fisheries)	21.9	14.5
Depressions	9.6	-
Freshwater fish and prawn ponds, paddies, fruit garden canals	-	102.0
Brackish water shrimp ponds	-	39.4
Brackish water fish ponds	-	11.0
Melalecuca forest area	14.5	-
Sea (including crab, clam and blood cockle fisheries)	264.6	2.5
Total	**310.6**	**169.4**

Source: GOV, WB, UNDP and Mekong Secretariat (1993), Master Plan for the Mekong Delta in Vietnam

Export of aquatic products is increasing rapidly. The 1991 yield and export quantities derived from them are presented below.

Table 3.17 Export of Fisheries Production in the Mekong Delta in 1991

(Unit: 1,000 ton)

Products	Fresh Material	Net Export
Frozen shrimp and prawn	53.6	26.8
Frozen fish	6.5	2.4
Dried shrimp	1.8	0.6
Other frozen products (including cuttlefish, squid)	5.5	1.8
Total	**67.4**	**31.6**

Source: GOV, WB, UNDP and Mekong Secretariat (1993), Master Plan for the Mekong Delta in Vietnam

3.11 Existing and Ongoing Water Resources Development Projects in the Mekong Delta

3.11.1 Major Water Resources Development Projects

The Mekong Delta has much potential for water resources development for agriculture. The following table shows the major water control projects proposed in the Perspectives for Mekong Development in 1988. The location map of projects is presented in Fig. 3.14. At present, several projects have been completed. The location map of existing irrigation facilities is also shown in Fig. 3.15.

Table 3.18 Main Water Control Projects in the Mekong Delta

Project		Major Water Control Measures				Area (ha)	Project Works
No	Name						
1	Cai San, Phase I	*			*	4,650	Construction of embankment (84km), dredging of canals (66.5km), installation of 16 large pumps, and construction of distribution system
2	Tiep Nhut		*		*	43,000	Upgrading of dikes, rehabilitation of salt prevention structures, dredging of main canals, and construction of distribution system
3	Phu Tan	*			*	4,375	Pilot scheme of Than Nong (61)
4	Than Nong	*			*	12,900	Construction of dikes (22.2km), 8 sluices, 6 main canals and a distribution system
5	Nam Xa Canal	*			*	14,451	Construction of dikes (53km), 11 canals (51km), and 8 sluices for flood control, drainage and water intake
6	Cai San-Thotnot	*		*	*	64,700	Rehabilitation of existing canals, and upgrading and construction of pump stations
7	Sau Dong		*		*	13,000	Construction of main canal (21.2km), upgrading of secondary canals (53km), construction of 23 sluices at the heads of main canal and secondary canals and construction of levees (52km)
8	Giong Rieng-Go Quao	*	*	*	*	44,400	Construction of main canal, pump stations, dikes for flood control and salinity prevention, and a secondary and tertiary irrigation system
9	Bac Hong Ngu	*			*	24,351	Construction and rehabilitation of canals, levees, drainage sluices and pumping stations
10	Tan Thanh	*		*	*	26,440	Rehabilitation of main canals, construction of 4 canals, 90 km levees and 11 sluice gates
11	Giong Trom-Ba Tri		*		*	16,900	Construction of 2 sluices for water supply and 6 drainage sluices, rehabilitation of main canal system, and construction of dikes and salinity control dams
12	Go Cong		*		*	28,053	Construction of head sluices and structures, canals, dikes and pumping stations
13	Huong My	*	*			9,916	Construction of a dam/ diking system (40 km) and 10 sluices, rehabilitation of main canal (29.5km) construction of pumping stations, and on-farm development

Note: 1.Flood control. 2. Salinity control. 3. Acidity control. 4. Irrigation

Source: Perspectives for Mekong Development, Interim Committee for Coordination of Investigations of Lower Mekong Basin, 1988

Several water control projects in the Mekong delta are introduced below.

3.11.2 Go Cong Water Control Project

The Go Cong Water Control Project is one of typical projects implemented in the salinity intrusion area of the Mekong Delta. The project started in 1976 and completed by the 1995 with a view of controlling the regular inundation and salinity early season crop. Canal system and six main sluices were constructed under the project. It was expected that triple-crop paddy cultivation could be introduced over the area of at least 35,000 ha, with production reaching 300,000 tons by the year 2000.

Photo: Van Gion Sluice of Go Cong Project

The project is located in Tien Giang Province and lies between the Mekong River and Vam Co-Soai Rap River as shown in Fig. 3.16. Both rivers are tidal and in the dry season salt sea water penetrates upstream as far as the Cho Gao canal. The project components are:

(1) Irrigation/drainage systems consisting of external drainage channels, internal canals and sluices: A total length of main canals is around 80 km.: Dyke system consists of 155 km, of which coastal dyke stretch is only 23 km.

(2) Salinity intrusion control system including 6 main sluices and dyke system: Dyke system consists of 155 km, of which coastal dyke stretch is only 23 km.

(3) Tidal irrigation by the canal system: Main sluices provide enough head for tidal irrigation to the major part of the area.

At present, almost 30,000 ha are cultivated under the summer-autumn crop and over 7,000 ha under the winter-spring crop, giving an overall cropping intensity of around 240%.

3.11.3 Quan Lo Phuong Hiep Water Control Project

The Quan Lo Phuong Hiep project (178,900 ha) is located at the downstream end of the Bassac River close to the coast. The aims of this water control project are to complete a system of works (building sluice gates on waterways entering the agricultural areas) that will prevent salinity intrusion in the dry season, and enhance drainage in the wet season. Without salinity control, farmers on large areas are at present limited to a single wet-season rice crop. With the project, there will be a considerable increase in double cropping of rice and also some increase in the triple cropped area. Framers will also have the opportunity to grow upland crops in the dry season as an alternative to rice. The location map of the project is shown in Fig. 3.17.

The sluices provided are of the type with vertical axis swing gates, and can be operated automatically by hydraulic heads created by each tide, or semi-automatically with manual intervention depending on the operating modes. In the dry season when the river flow levels are low and outside salinity levels are high, the gates are kept mostly closed and opened periodically to freshen the water in the upstream gates. In the wet season, the gates can be set to open at low tide to drain water and to close at high tide. In addition to salinity control, the sluices would improve drainage significantly by removing large net excess outflows to the sea at each tide cycle.

3.12 Issues on Water Resources Management in the Mekong Delta

Although there are a number of existing issues on water resources development and management in the Mekong Delta, three issues; namely, (i) water shortage in the dry season,(ii) seawater intrusion in the dry season, and (iii) acidification, are necessary to be highlighted in view of the evaluation of maintenance of flows on the Mekong River. These three issues are easily likely to intensify in the near future by impacts of various planned water resources developments in upstream riparian countries.

3.12.1 Dry Season Water Shortage

During the early and end parts of the dry season (January to June), the discharges of the Mekong are adequate to meet water requirements for irrigation supply. However, local water shortages occur during the mid-dry season (early March to May), because the water demand for irrigation coincides with the minimum Mekong flows. From February to April the Mekong discharge gradually decreases to the lowest in April (detail discussion is made in Chapter 5). The intensification of agriculture from single crops to double crops and from double crops to triple crops is increasing the dry season water demand.

3.12.2 Salinity Intrusion

During the dry season saline water from the South China Sea and the Gulf of Thailand moves upstream along the rivers and canals of the Mekong Delta. The salinity intrusion into the Mekong Delta is very complicated. The highest salinity is usually observed in April. Currently 1.7 million ha of the delta lands are affected by saltwater intrusion, which not only affects irrigation development but also domestic water supply. Salinity reduces water quality and damages croplands. The problem is most severe during the low flow season when there is not enough flow to prevent seawater intrusion. Strong tidal waters penetrate up to 50-70 km. The existing engineering infrastructure will be inadequate for coping with salinity intrusion, if water abstraction increases in the delta. The area affected by salinity is expected to increase to 2.2 million ha, if preventive measures are not taken up. Fig. 3.18 presents the affected area by saltwater intrusion in the Mekong Delta.

Generally the water with salinity higher than 4 g/l could not be used for irrigation. Penetration of 4 g/l isohaline from the sea may reach as far as 29.4 km in the Co Chien branch, 26.4 km in the Ham Luong branch, 26.2 km in the Cua Dai branch, 43.2 km in the Cua Tieu branch, and 25.6 km in the Bassac. Salinity intrusion impacts are different for each year, depending on not only hydro-meteorological conditions, but also on the water abstraction from the river that can cause the decrease of flow to make deeper salinity intrusion. Thus increase of water use in the dry season means to lower the Mekong flow that coincides with increase of salinity intrusion impacts. This is a conflict between development and protection of water resource.

3.12.3 Acidification

One major water quality issue in the delta is the acidity generated by the acid-sulphate soils and the associated low pH levels and high levels of Fe, Al and SO_4. About half of the soils of the delta are acid-sulphate soils. Of these, about one-half are classified as “severe” acid soils. Acid-sulphate soils generate acidity naturally. However, this process is exacerbated by the construction of canals, embankments and raised agricultural beds. There is some evidence that the general quality of Mekong water in the delta is declining. There appears to be significant contamination with organic wastes (animal and human) in localized areas, leading to low DO levels and high levels of faecal coliforms.

4. SALINITY MEASUREMENTS AND SALINITY INTRUSION IN THE MEKONG DELTA

4.1 Historical Background of Salinity Measurements and Studies in the Mekong Delta

In the period 1935-1954, salinity was observed at the stations established by the French consultant in the main branches and important canals. Subsequently, Sogreah collected salinity data (Mathematical Model of the Mekong Delta in 1962-1965 by UNESCO). Under this modeling study, the salinity measurement campaign was carried out at 23 stations in 1964. The salinity samples were taken every Monday almost at high water and low water (usually 4 times at 8 a.m., 11 a.m., 14 p.m. and 17 p.m.). The samples were taken near the riverbank 0.4 m below the water surface. Salinity was determined by chemical reaction. Further isohalines of 1 g/l and 4 g/l in the whole delta were firstly established. A total of 1,730 samples were taken and analyzed. The first hydraulic model for the Mekong Delta was developed under the study (Sogreah Model).

In 1973-1974, the Netherlands Delta Development Team established 30 salinity stations in the main rivers for investigation (Recommendations Concerning Agricultural Development with Improved Water Control in the Mekong Delta in 1974). The National Committee on Hydrology intensively carried out a salinity measurement campaign to provide data to the team. Measurements were made simultaneously at every five stations along the rivers. Salinity was measured vertically in the middle of river or at a place 1/3 of river, and 3 locations along the water surface, mid-depth and bottom of vertical were measured in every 30 minutes.

In the period 1977-1979, salinity measurement has largely developed. Totally, 75 stations were established in the entire delta area. Samples were taken at the water surface, the mid-depth and the bottom, and at high tide and low tide every month. The samples were analyzed by salinometer.

From 1981 to 1992, within the framework of international cooperation of the Interim Mekong Committee, and with technical and financial assistance from the Government of Australia since 1985, the Programme of Salinity Intrusion Studies in the Mekong Delta was carried out with three objectives to:

(1) Set up a salinity monitoring network in the Mekong Delta

(2) Provide forecasts for users concerned, and

(3) Strengthen the capabilities of Vietnamese authorities on salinity intrusion forecasting operations and related activities.

Subsequently the findings and many study results lead to the implementation of the Salinity Forecasting Project in 1988-1995 with assistance again from the Government of Australia. Under the program, the Sub-Institute of Water Resources Planning (SIWRP) developed an one-dimensional unsteady flow hydraulic model of the major river and canal systems in the Mekong Delta (Vietnam River System And Plain: VRSAP model). Further the SAL computer program (SAL model) was developed by Dr. Nguyen Tat Dac to simulate flows, salinity intrusion, BOD and propagation of acid water. These models are valuable planning tools and can be used to investigate the effects of low flows and salinity control structures. The SAL model is more suitable for simulations of salinity intrusion for large hydraulic systems such as the Mekong Delta (complex system of rivers and irrigation canals). These significant projects are described in detail in succeeding subsections. Table 4.1 presents the summary of salinity measurement activities under the Salinity Forecasting Project.

At present, the Southern Region Hydro-Meteorological Centre (SRHMC) in Ho Chi Minh City undertakes salinity measurement as well as hydro-meteorological observation. SRHMC measures 35 salinity stations within its area of responsibility including the Mekong Delta as listed in Table 4.2. Out of 35 stations, 28 stations are located in the delta area covering 7 provinces with a view to providing salinity intrusion forecasts (MEKSAL model) to the water users. Each station has been equipped with salinometer for direct measurement and radio transceiver. Salinity is being measured hourly on some strong tidal days or whole days in the dry season. Weekly forecasts are disseminated to various agencies such as the Provincial Party Committee and the People's Committee, which are specialized agencies on the provincial, district and community levels. The location map of salinity measurement stations is shown in Fig. 4.1. The spatial distribution of station is summarized below.

Table 4.3 Number of Salinity Stations by Branch in the Mekong Delta

Branch in the Delta	No. of Salinity Station
Vam Co River	4
Cua Tieu	6
Cua Dai	2
Ba Lai	1
Ham Luong	2
Co Chien/ Cung Hau	4
Bassac/Cua Dinh An	4
Inland canal/small river	12
Total	**35**

Source: WUP-JICA Study Team

4.2 Salinity Condition in the Mekong Delta

4.2.1 Type of Mixing Conditions

Saltwater intrusion is a natural phenomenon in rivers with bottom elevation below mean sea level. It is basically caused by the difference in density between saltwater (approximately 1.03) and freshwater (approximately 1.0). Saltwater intrusion is affected by other factors such as the river flow and duration, elevation of thalweg, slope of river channel, tidal magnitude, wind velocity and direction, and water temperature. Of these factors, the river flow is dominant.

In the rivers with a long duration of high flows, freshwater is able to prevent saltwater from intrusion into the river channel. If the volume of freshwater is large enough, freshwater can push saltwater away from the river mouth. On the contrary, saltwater can intrude easily into the rivers with a long duration of low flows. Because saltwater is heavier than freshwater, it moves upstream along the river bottom under floating freshwater.

There are three types of mixing of river water and seawater over the depth in river mouths; namely, (i) well (complete) mixed, (ii) partially (moderate) mixed, and (iii) saltwater wedge. They are based on the relationship between the fresh water inflow and the corresponding salinity distribution entering from the sea as illustrated below.

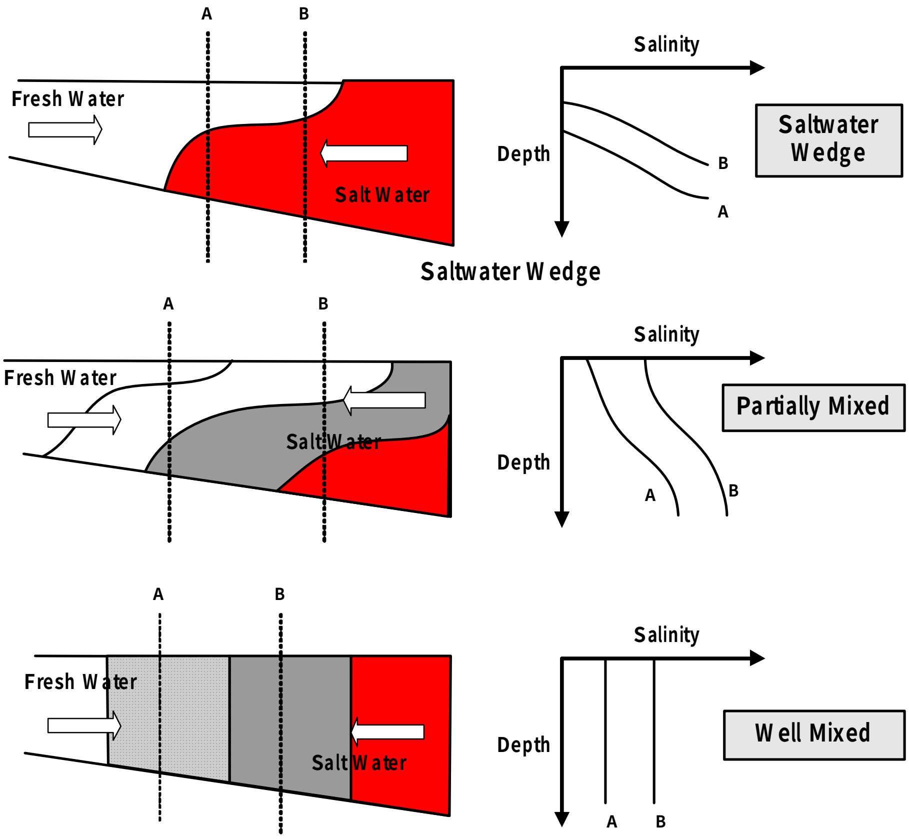


Fig. 4.2 Seawater Mixing with Salinity Distribution

Marked characteristics of mixing conditions are summarized in terms of salinity distribution, as follows:

Well-mixed condition: When the salinity distribution changes slightly (or almost homogeneous) over the river depth, it is called a well-mixed condition. Vertical stratification of salinity density is generally smooth.

Partially mixed condition: When the salinity density continuously increases from the surface to bottom, it is called a partially mixed condition. The flow is moderately stratified or different salinity concentrations are usually divided into different layers.

Saltwater wedge condition: When the salinity density changes sharply at the interface between upper layer of fresh water and underlying layer of saltwater, it is called a saltwater wedge condition. A clear interface between saltwater and fresh water is formed because the river flow is being strongly stratified.

Typically, a high-stratified wedge may be formed in deep rivers with high freshwater flows. The leading edge of the saltwater wedge is well defined, however, some mixing occurs to form a brackish water region along the freshwater-saltwater interface. The shape of saltwater wedge may be changed by other factors, particularly the river flow and tides. In the rivers without freshwater flow, saltwater will intrude into the river channel to the point where the elevation of the river bottom is at the sea level. The most undesirable characteristics of saltwater intrusion is that it is easy to intrude but difficult retreat.

4.2.2 Mixing Conditions of Mekong Delta Estuaries

Topographic, hydrologic, and climatic conditions in the Mekong Delta are generally favorable for saltwater intrusion. The river bottom is below the mean sea level and very flat. The tidal magnitude is high, approximately 3.0 m in the South China Sea. During the dry season, the wind has a southwest-northeast direction, which is opposite to the direction of freshwater flow in the Mekong River.

In general, type of mixing condition changes both in time and over the area of river mouth. Governing factors are river discharge variation, tidal fluctuation and tidal phase, wind, and waves. A well-mixed condition usually occurs with strong tide and small fresh water. In contrast, stratification phenomena of partially mixed conditions appear when fresh water increases and the saltwater entering from the sea decreases. The saltwater tends to sink forming underlying layer because the saltwater is of higher density than the fresh water.

The actual mixing conditions in the Mekong branches were investigated through several campaigns for salinity measurement in the framework of the Programme of Salinity Intrusion Studies. The measurements were conducted in 1985, 1986, 1989 and 1991. The measured vertical salinity distributions along the Co Chien branch in February 1989 are shown below.

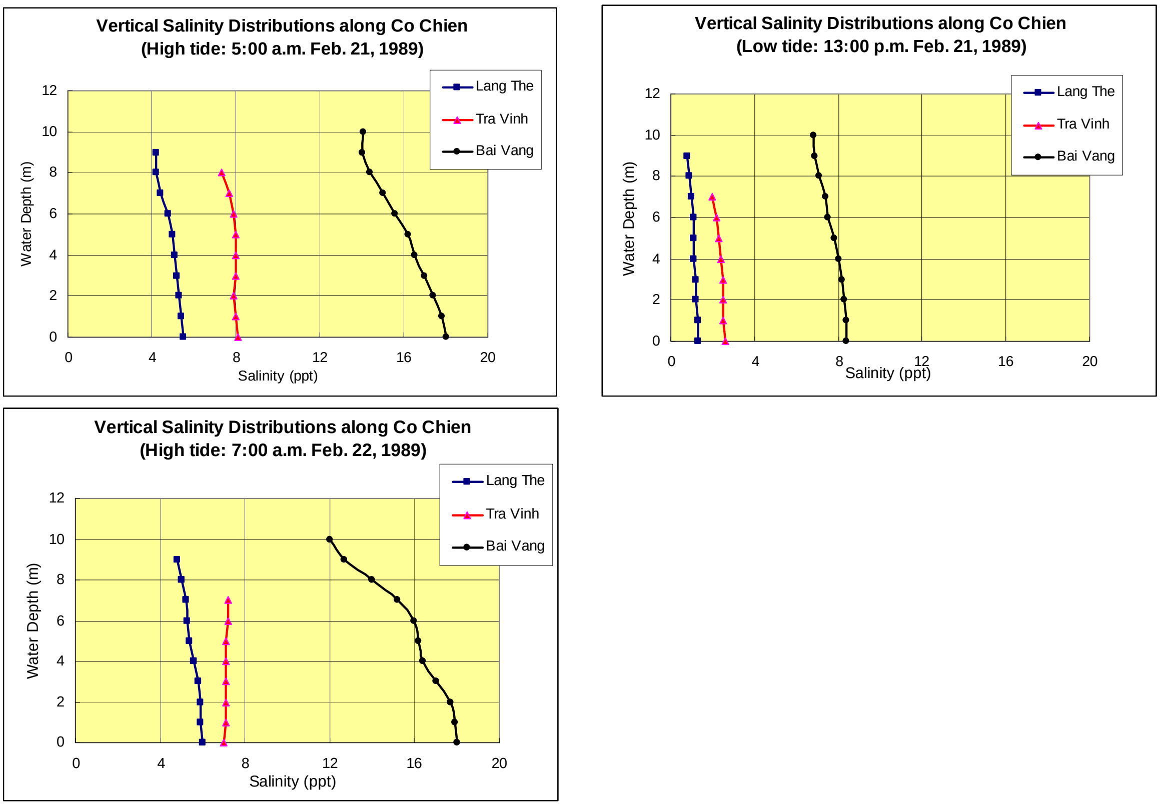


Fig. 4.3 Vertical Salinity Distribution along Co Chien Branch in the Mekong Delta (February 1989)

As seen above, the salinity mixing condition in the Co Chien branch in February shows well-mixed or partially mixed conditions. The estimated actual mixing conditions in the Mekong Delta branches in the dry season are summarized below. It is noted that the evaluation of mixing conditions isbased on the mixing analysis using various mixing parameters.

Table 4.4 Summary of Salinity Mixing Conditions in the Mekong Branches

Year	Month	Branch	Station	Discharge (m3/s)	Mixed Condition
1985	April 1- 15	Cua Tieu	V. Giong	66	Well mixed
		Cua Dai	Giao Hoa	349	Well mixed
		Cua Dai	Xuan Hoa	349	Well mixed
		Ham Luong	My Hoa	470	Well mixed
		Bassac	Long Phu	352	Partially mixed
		Bassac	Dai Ngai	352	Well mixed
		Cung Hau	Anlac Tay	887	Well mixed
1986	March 29 – April 11	Cua Tieu	Hoa Binh	50	Well mixed
		Cua Dai	Loc Thuan	260	Well mixed
		Cua Dai	Xuan Hoa	330	Well mixed
		Ham Luong	My Hoa	277	Well mixed
		Ham Luong	Son Hoa	282	Well mixed
		Co Chien	Bai Vang	170	Well mixed
		Co Chien	Tra Vinh	549	Partially mixed
		Bassac	Ngan Ro	295	Well mixed
		Bassac	Long Phu	300	Partially mixed
		Bassac	Dai Ngai	330	Partially mixed
		Cung Hau	Anlac Tay	884	Well mixed
1989	February 10 - 24 (10/2-24/2)	Co Chien	Bai Vang	312	Partially mixed
		Co Chien	Tra Vinh	777	Well mixed
		Co Chien	Lang The	780	Partially mixed
	June 10 -25	Co Chien	Bai Vanh	827	Partially mixed
		Co Chien	Tra Vinh	1,864	Partially mixed
1991	June 9 - 24	Co Chien	Tra Vinh	1,900	Partially mixed
		Bassac	Dai Ngai	1,600	Partially mixed

Source: Estimation of Mixing Conditions in the Mekong Estuary System, Programme of Salinity Intrusion Studies in the Mekong Delta Phase III, SIWRPM, 1992

The following observations were drawn from the related reports with regard to the mixing conditions in the dry season:

(1) Based on the investigation results, there was no evidence showing the occurrence of highly stratified or salt wedge phenomena in the Mekong estuary system.

(2) The reason for the absence of saltwater wedge might be strong tidal effects (amplitude from 2 m to more than 3 m) and relatively sharp topography (6 m to 8 m in depth) at the Mekong estuary system.

(3) Partially mixed conditions occurs stronger after high water level, which occurs subsequently after a higher low water level. This can be explained that tidal amplitude from a higher low water level to the subsequent high water level.

(4) In April of two years 1985 and 1986, well-mixed conditions occurred in almost all branches, though there was a minor partially mixed phenomena in the Bassac branch (Cua Tran De branch).

(5) In the months of February and June in1989 and 1991, partially mixed conditions became clear and occurred almost at the time of tidal cycles except at Tra Vinh in the Co Chien branch.

4.2.3 Salinity Conditions in the South China Sea (East Sea)

The salinity of seawater is around 29 to 33 g/l (29,000 to 33,000 ppm). Monthly mean salinity records of seawater are available for four years at Con Dao in the South China Sea. Con Dao is located in a small island in the South China Sea and thus not affected by fresh water. As seen below, the monthly mean salinity does not change so much and is in the range between 29.0 and 33 g/l. It is said that throughout the dry season from January to April, the seawater salinity in the South China Sea is almost constant.

Table 4.5 Monthly Mean Salinity of Seawater at Con Dao in the Mekong Delta

(Unit: g/l)

Month	1985	1986	1989	1990
Jan	32.4	32.7	32.7	32.4
Feb	21.1	32.6	32.7	32.4
Mar	32.1	32.5	32.5	32.6
Apr	32.1	32.7	32.5	32.7
May	-	32.5	32.2	32.6
Jun	31.6	32.2	32.0	32.0
Jul	-	31.6	31.6	31.7
Aug	-	31.5	31.3	31.7
Sep	30.8	31.2	31.1	-
Oct	29.0	30.8	30.5	29.8
Nov	-	31.3	31.1	-
Dec	31.6	32.2	32.2	-
Max. difference	**3.4**	**1.9**	**2.2**	**2.6**

Source: Analysis of Salinity Intrusion Length, Programme of Salinity Intrusion Studies in the Mekong Delta Phase III, SIWRPM, 1992

4.2.4 Salinity Conditions along the Delta Seashore

In view of the obvious influence of fresh water from the river mouth, salinity along the seashore becomes lower than that in the South China Sea. In the dry season from February to April, the salinity at the seashore gradually increases due to decreased fresh flow and predominant north-east and east winds. On the contrary, in the rainy season in August and September when the Mekong discharges are highest, the salinity decreases.

The general salinity conditions offshore the Mekong Delta are estimated based on the offshore measurements in 1974, as presented below (A Special Study on Predictability of Salinity Intrusion in the Mekong Estuarine System, Interim Mekong Committee, 1987):

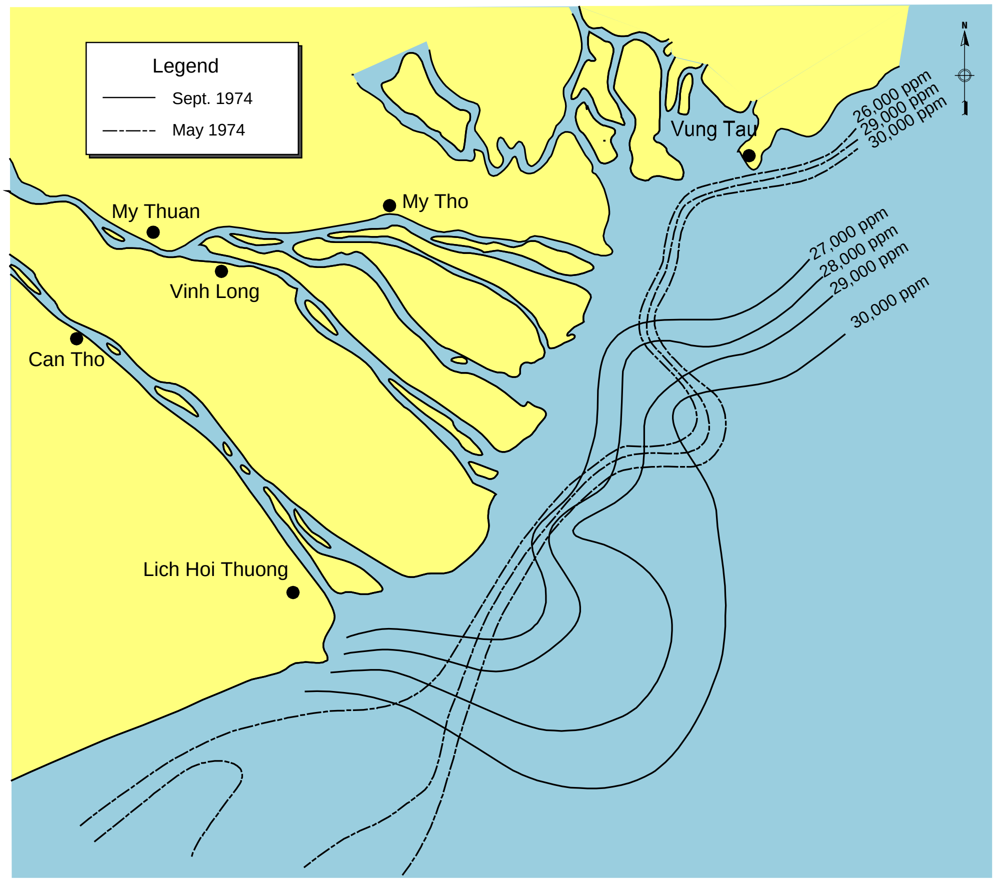


Fig. 4.4 Salinity Condition along Seashore in the Mekong Delta

4.2.5 Seasonal Variation of Salinity in the Mekong Delta

Long-term plots of maximum salinity data are available at the Tan An station in the west Vam Co River, one of the drainage routes of the Mekong Delta (Interim Mekong Committee, 1988, Delta Salinity Studies, Phase II). Plots are shown below.

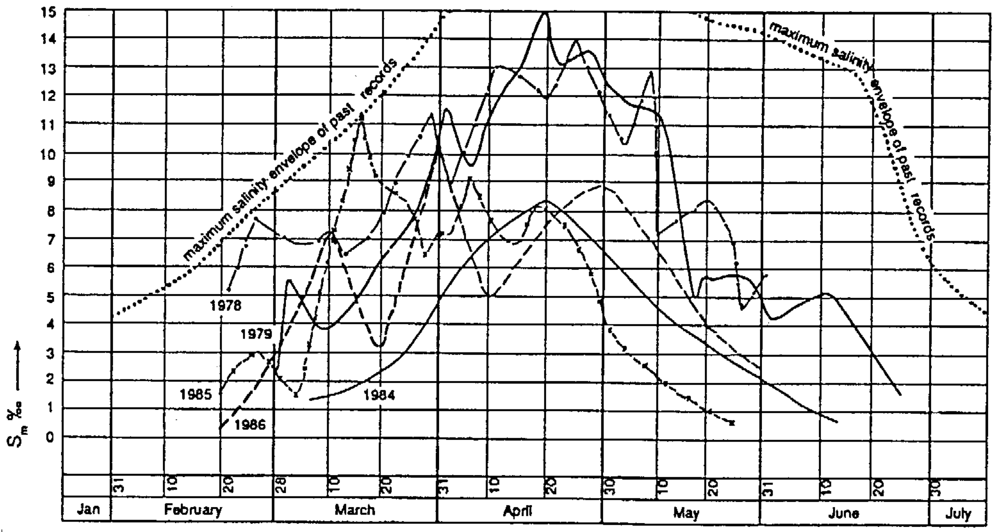


Fig. 4.5 Variation of Maximum Salinity at Tan An in the West Vam Co River in the Mekong Delta

The experience in the Mekong Delta has shown that an increase in the flow during the dry season can substantially reduce seawater intrusion as shown above. The West Vam Co River flows through the Plain of Reeds in the delta. This area is characterized by the very low flows during the dry season resulting from its relatively small watershed compared to the Mekong River watershed. Due to this, seawater intrudes into the Plain of Reeds via the West Vam Co River and the 1 g/l salinity level can penetrate up to 150 km inland. As seen above, significant salinity intrusion persists for three months (March to May).

Besides, the measured hourly salinity data at three major stations in 2001 were obtained from the Hydro-meteorological Data Centre in Hanoi. They are Binh Dai in the Cua Dai branch, Tra Vinh in the Co Chien branch and Dai Ngai in Bassac River. Due to budgetary limitation in recent years, measurements have been made on hourly basis several times per month in the dry season. The duration of measurement is around 3-10 days. The measurement records are presented in Table 4.6. Maximum hourly salinity is plotted at three stations, as shown below.

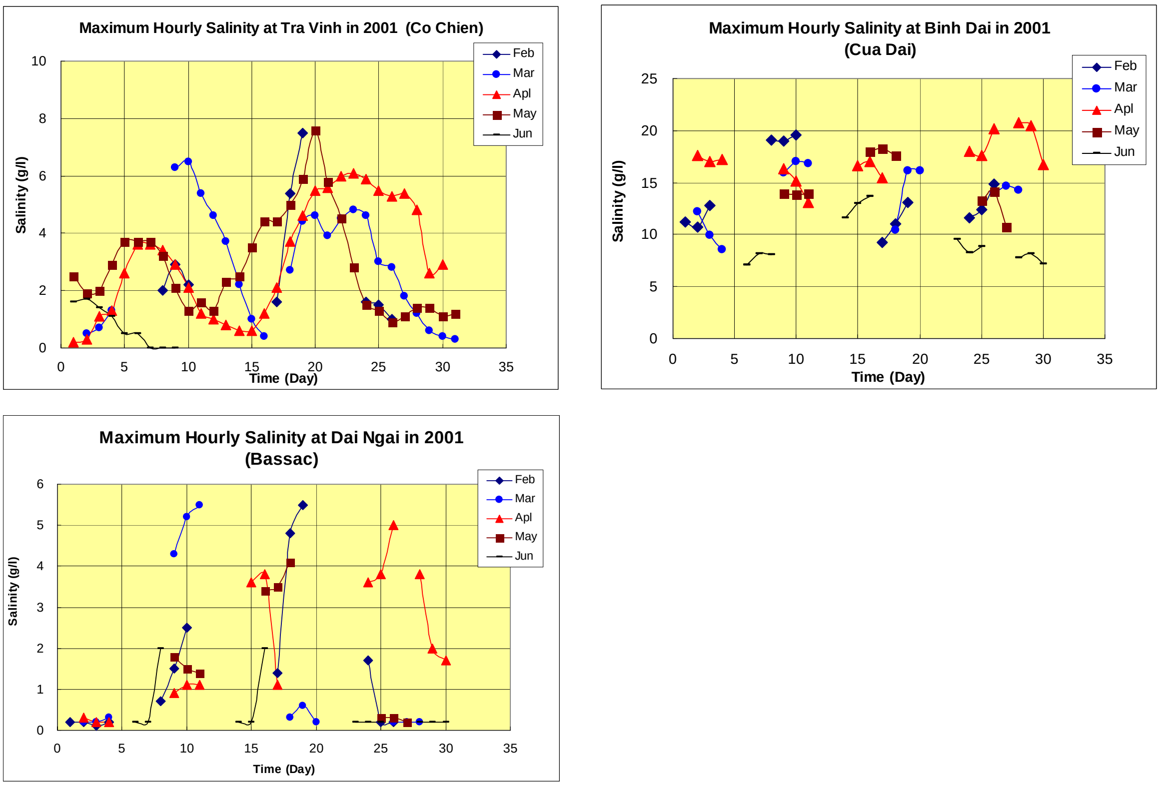


Fig. 4.6 Plots of Maximum Salinity in Mekong Branches and Bassac River

Table 4.7 Summary of Dry Season Salinity Measurement Campaign in the Mekong Delta in 1989 and 1990

Station	Mean Salinity (g/l)	Maximum		Minimum		Standard Deviation (g/l)
		Salinity (g/l)	Date	Salinity (g/l)	Date	
Year 1989						
An Thuan	16.86	25.00	April 10	6.50	June 8	4.33
Tan Huong	5.88	10.40	April 10	1.30	June 5	2.24
Phu Khanh	8.45	14.8	March 30	0.30	June 8	3.32
Ben Trai	16.60	25.80	April 11	7.00	June 6	4.53
Hung My	7.11	11.80	April 8	0.20	June 5	3.25
Tra Vinh	4.73	12.00	April 10	0.20	June 5	2.20
Huong My	6.01	10.50	April 10	0.30	June 4	2.70
VamThom	1.11	3.00	April 5	0.00	June 6	0.75
Da Loc	4.78	7.50	May 21	1.50	June 15	1/44
Cau Quan	3.03	6.80	May 9	0.00	June 10	1.97
Tieu Can	1.64	4.20	March 19	0.90	June 4	0.60
Year 1990						
An Thuan	16.01	26.00	April 28	5.80	Feb 20	4.76
Tan Huong	5.81	14.30	April 30	1.10	June 9	2.72
Phu Khanh	10.08	23.00	April 29	0.70	June 11	4.64
Ben Trai	17.22	26.00	March 13	3.80	Feb 18	4.84
Hung My	8.54	19.60	April 29	1.00	June 11	3.42
Tra Vinh	6.41	14.60	April 29	0.00	June 10	2.74
Huong My	5.59	13.70	April 28	0.00	Feb 16	2.68
VamThom	1.31	7.00	April 29	0.00	Feb 14	1.33
Da Loc	10.08	23.00	April 30	0.00	June 11	4.54
Cau Quan	3.86	12.90	April 20	0.00	May 31	2.29
Tieu Can	1.79	5.40	May 1	0.30	March 1	0.99

Source: Salinity Forecast in the Lower Mekong Basin, Programme of Salinity Intrusion Studies in the Mekong Delta Phase III, SIWRPM, 1992

In 2001, the maximum salinity in the Mekong River occurred in April and May, and in March in the Bassac River. Under the Programme of Salinity Intrusion Studies, measurement campaign was carried out in two dry seasons in 1989 and 1990. The results are summarized in Table 4.7. Apart from several stations, the maximum salinity often occurs in April, when the tide varies most strongly and the Mekong discharge becomes lowest. An increase in the Mekong discharge toward the end of dry season tends to substantially reduce seawater intrusion.

Salinity variations in the dry season were measured at major stations under the measurement campaign in 1990, as summarized below.

Table 4.8 15-day Average Salinity in the Mekong Delta in the 1990 Dry Season

Period	Total Discharge	Salinity (g/l)				
		My Tho	Xuan Hoa	My Hoa	Tra Vinh	Dai Ngai
Feb 1st	4,100	0.16	0.59	0.78	2.03	0.36
Feb 2nd	3,170	0.21	0.71	1.22	2.86	0.68
Mar 1st	2,550	0.75	2.09	1.11	2.83	2.64
Mar 2nd	2,070	0.50	1.47	1.54	3.57	3.51
Apr 1st	1,930	0.65	1.74	1.65	4.56	2.89
Apr 2nd	1,570	1.49	2.86	3.13	5.57	2.96
May 1st	2,340	1.95	3.87	2.24	5.48	3.48
May 2nd	3,600	0.47	1.31	0.88	2.83	1.38

Source: Some Fundamental Hydrodynamic Characteristics of the Mekong Delta Water System during the Dry Season, Programme of Salinity Intrusion Studies in the Mekong Delta Phase III, SIWRPM, 1992

Variation of salinity above is illustrated in Fig. 4.7 below. As seen, due to decrease of the Mekong flow in the dry season, seawater intrudes further upstream of the Mekong branches.

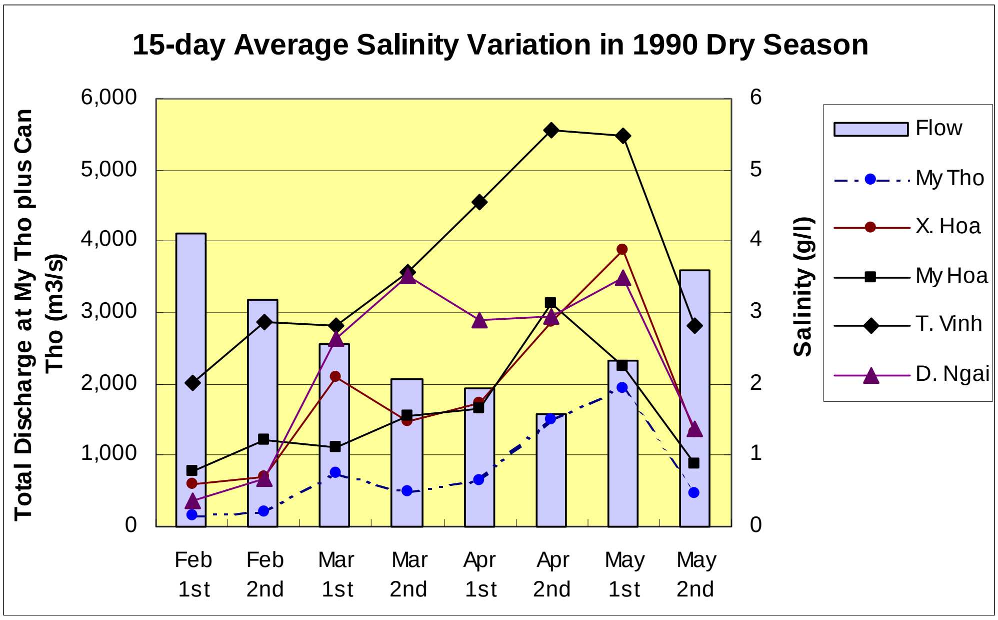


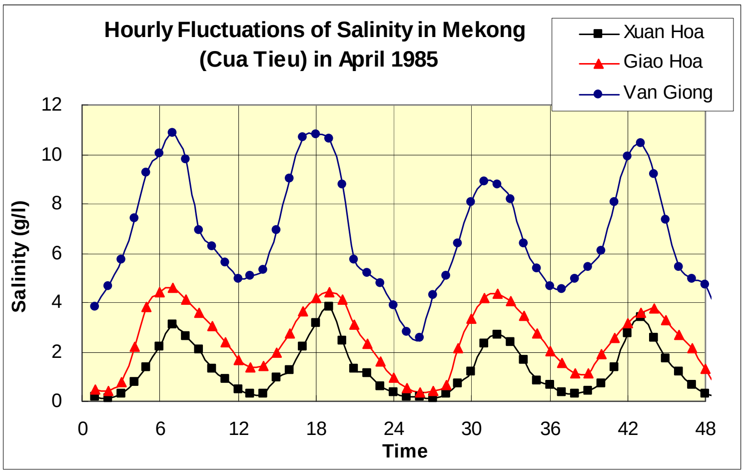
Fig. 4.7 15-day Average Salinity in Mekong Delta in the 1990 Dry Season

4.3 Salinity Intrusion Studies in the Mekong Delta

The upstream Mekong River discharge affects salinity intrusion in the Mekong Delta. The Mekong discharge in general varies from 2,000 m^3/s in April to over 40,000 m^3/s in September. Due to decrease of the flow of the Mekong mainstream in the dry season, seawater intrudes further upstream of the Mekong branches as well as the Ca Mau peninsula. However during the wet season, saline river water containing over 4 g/l is observed in a narrow belt in the coastal area in the southern part of the Ca Mau peninsula. It is generally said in Vietnam that the fresh water with salinity higher than 4 g/l could not be used for irrigation. The Mekong flow becomes lowest in April and thus, the highest salinity is usually observed in April. It is said that the 4 g/l saline level typically penetrates 30-40 km upstream along the Mekong branches as well as the Bassac River. The general conditions of salinity intrusion and distribution in the delta are shown in Figs. 4.8 and 4.9. These facts call for water control to exclude salt water from the existing delta canals and prevent the tidal water from entering onto the existing agricultural lands. As introduced in subsection 2.8, various water control projects have been undertaken to minimize salinity intrusion in the lower delta areas. As shown in Fig. 4.9, the area not affected by 4 g/l saline water level is less than 50% of the Mekong Delta during the dry season. In the delta there is a wide annual variation in salinity intrusion depending on the Mekong flow and sea level variations.

Plotted below are hourly salinity fluctuations along both the Mekong and Bassac Rivers in April 1985. The Interim Mekong Committee Secretariat bases this observation on the simultaneous salinity measurement campaign in 1985.

Vam Giong and Xuan Hoa are located at around 28 km and 44 km from the Mekong estuary. In the Bassac River, Long Phu, Dai Ngai and An Lac Tay are located at 29 km, 43 km and 62 km, respectively. In the dry season in the Mekong (Cua Tieu branch), the upper limit of salinity of 4 g/l reaches up to 40 km from the river mouth. At An Lac Tay in the Bassac River located at over 60 km from the estuary, penetration of seawater is not significant being below 1 g/l.



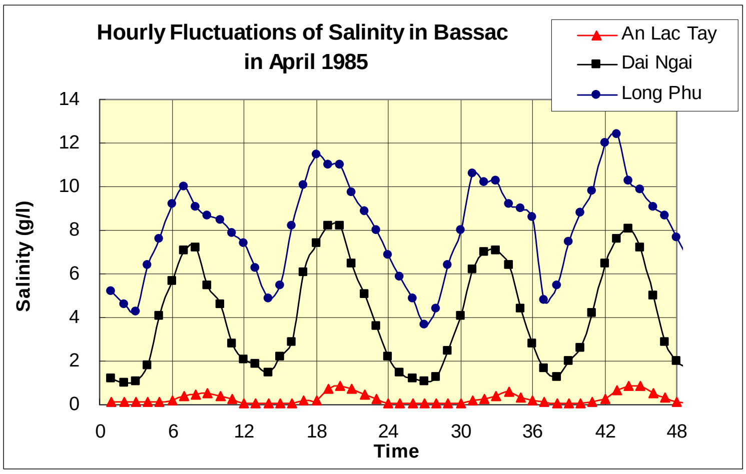


Fig. 4.10 Fluctuation of Hourly Salinity in the Mekong and Bassac Rivers in April 1985

The salinity intrusion into the Mekong Delta is very complicated. The upstream penetration of salinity along rivers and canals are likely to limit to provide freshwater for irrigation and other uses. The salinity problems have been one of the main focuses of the water resources development projects in the Mekong Delta in which studies on salinity intrusion and salinity forecasting play an important role for minimizing the adverse effects due to salinity intrusion. A number of studies on salinity intrusion along the major delta branches and canals have been thus undertaken mainly since 1970s. In particular, the salinity intrusion was intensively studied under the Programme of Salinity Intrusion Studies in order to improve the effectiveness of the existing water control works in the delta and to enable better coordination of water resources exploitation for limiting possible adverse effects of salinity intrusion. As a result of such studies, the mechanism and consequences of salinity intrusion were adequately understood. The major outcomes of past studies on salinity intrusion length are summarized below.

4.3.1 Measurement Campaign by the French Consultant in 1935-1954

A dense observation network of salinity station was established along the main branches to obtain the salinity variation in space and in time. The salinity samples were taken every Monday at high water and low water levels. As a result, the salinity isohalines of 1 g/l and 4 g/l in the whole delta was firstly established. Historic salinity measurement records are presented in Table 4.9. The location map of salinity measurement points is given in Fig. 4.11.

4.3.2 Studies carried out by the Netherlands Team in 1973-1974

In this project, salinity intrusion length was preliminarily studied. This study was the first approximation of seawater intrusion length. The regressions between the length of salinity intrusion and the total discharge “Qp” downstream Phnom Penh, based on the salinity data in 1936-1942, were established by applying the empirical methods. These regressions were used to determine the length of salinity intrusion in all main branches corresponding to the estimated Qp = 2,000 m^3/s and Qp = 6,000 m^3/s. By applying the statistical analysis method, the following length of salinity intrusion was determined from the salinity distribution curves:

Table 4.10 Approximate Length of Salinity Intrusion (1936-1942) in Major Rivers in the Mekong Delta

(Unit: km)

River	Qp = 2,000 m^3/s		Qp = 6,000 m^3/s	
	4 g/l	1 g/l	4 g/l	1 g/l
Cua Tieu	50	65	30	40
Ham Luon	40	55	25	30
Co Chien	35-45	50-55	25	30
Bassac (Hau)	45-55	55-65	20	40

Note: Qp is the estimated Mekong discharge downstream of Phnom Penh.
Source: Recommendations Concerning Agricultural Development with Improved Water Control in the Mekong Delta, Working Paper IV, Hydrology, The Netherlands Delta Development Team, April 1974

High salinity distribution curves were approximated for all the branches of the Mekong except for the Cua Dai branch as function of Qp, based on the month averages of the results of measurements at the banks during the years 1936 through 1942 and on the conductivity measurements in the year 1973. Figure 4.12 in the next page presents the salinity distribution curves of the Cua Tieu branch.

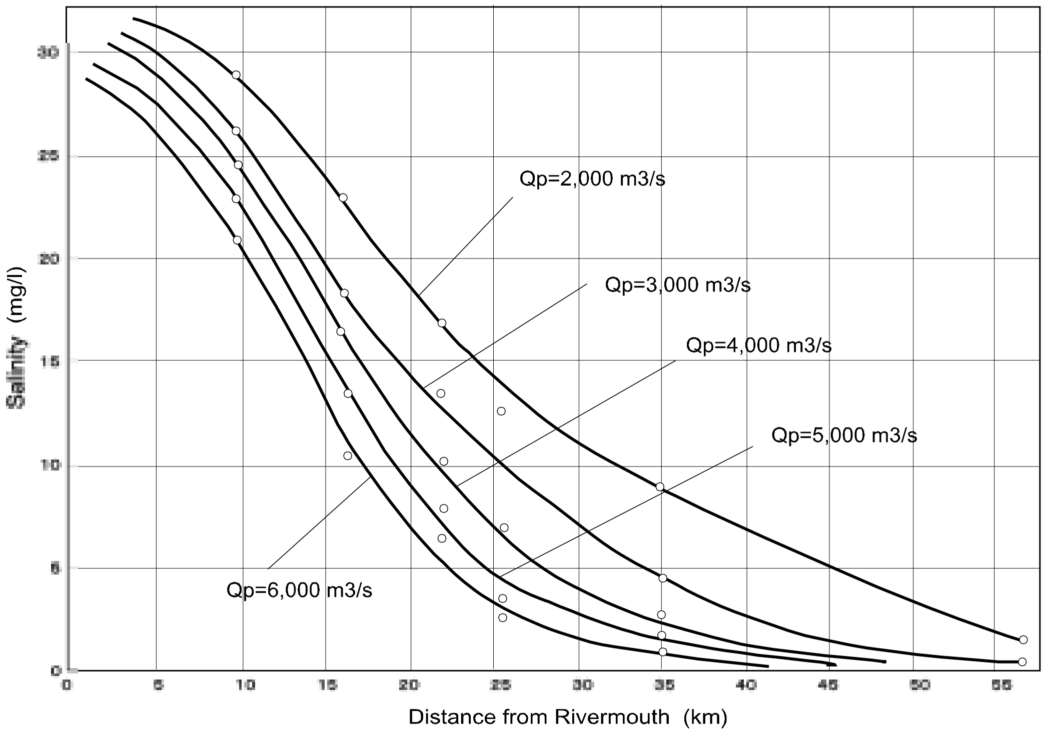


Fig. 4.12 High Salinity Distribution Curves in the Mekong Delta (Cua Tieu Branch) with Different Discharges at Phnom Penh

4.3.3 Studies Carried out by the General Department of Hydro-Meteorology in 1982

Using the statistical method, the study results on salinity intrusion were presented in the Phase I Workshop of Salinity Intrusion Studies. The estimated monthly average length of salinity intrusion (4 g/l) is given below. The study concluded that compared with salinity data in 1936-1942, salinity intrusion length in 1978-1982 was larger in the Mekong River, but smaller in Bassac River. To explain this phenomenon, the Department assumed that the discharge distribution rate of the Bassac River was increased. Monthly isohaline for salinity 4 g/l as shown in Fig. 4.9 is prepared under this studies.

Table 4.11 Monthly Average Length of Salinity Intrusion (4 g/l) in the Mekong Delta, 1977-1982

(Unit: km)

River	Month				
	Jan	Feb	Mar	Apr	May
Cua Tieu	27	39	48	52	50
Cua Dai	16	24	26	30	25
Ham Luon	16	24	28	34	30
Co Chien	20	26	31	37	24
Bassac	20	24	26	31	24

Source: Analysis of Salinity Intrusion Length, Programme of Salinity Intrusion Studies in the Mekong Delta Phase III, Sub-Institute of Water Resources Planning and Management, 1992

4.3.4 Studies Carried Out by SIWRP in 1981-1992

Based on the salinity measurement campaigns in 1985-1990, monthly average and maximum salinity intrusion curves were developed for each branch. Normally, the salinity intrusion length in all branches reached the maximum value in March or April corresponding to the lowest fresh water of the Mekong and Bassac. The developed curves are presented below.

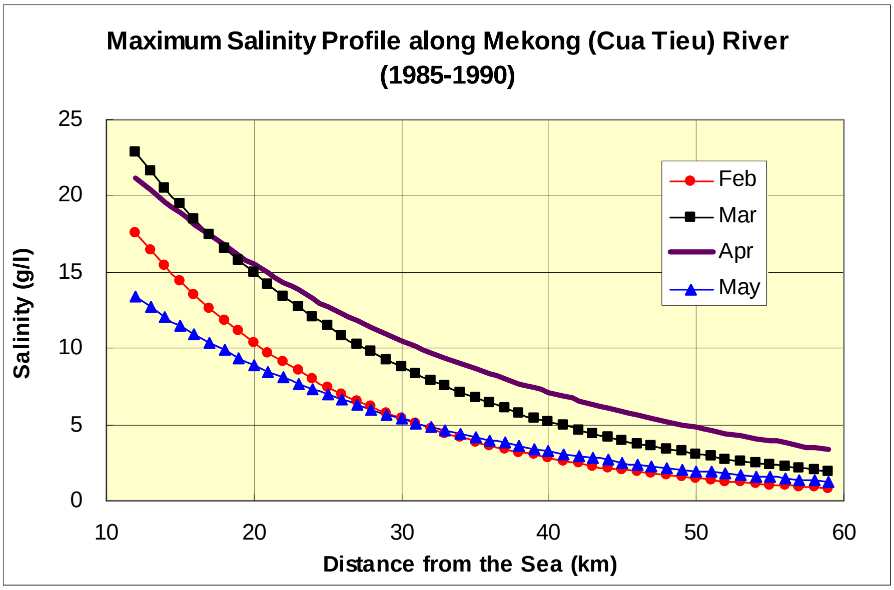


Fig. 4.13 Longitudinal Profiles of Maximum Salinity Distribution in the Mekong and Bassac Rivers

The limits of salinity intrusion of 4 g/l and 1 g/l were estimated as listed below.

Table 4.12 Monthly Average Length of Salinity Intrusion in the Mekong Delta in 1985-1990

(Unit: km)

River	Limit of 4 g/l (4,000 ppm)				Limit of 1 g/l (1,000 ppm)			
	Feb	Mar	Apr	May	Feb	Mar	Apr	May
Cua Tieu	23	32	37	32	43	51	59	56
Ham Luon	22	30	34	26	46	51	57	54
Co Chien	22	31	35	27	44	48	55	51
Bassac	25	32	33	26	44	54	58	51

Source: Analysis of Salinity Intrusion Length, Programme of Salinity Intrusion Studies in the Mekong Delta Phase III, Sub-Institute of Water Resources Planning and Management, 1992

Estimated intrusion length above shows that the intrusion limits of 4 g/l and 1 g/l in 1985-1990 are not much different from those estimated in 1977-1982. It was concluded however that in the recent years, the fresh water discharge seemed to decrease and the water extraction in the Mekong Delta was increased; hence, longer maximum salinity intrusion lengths were reasonable. It was estimated that the total area affected by seawater intrusion were approximately 17,000 km^2 in salinity of 4 g/l and 21,000 km^2 in 1 g/l.

Table 4.13 presents the summary of monthly average salinity along the major Mekong branches under the measurement campaign undertaken in 1985-1990. The extent of salinity intrusion in the delta varies every month during the dry season. Fig. 4.14 and 4.15 show the monthly upper limit of maximum salinity in both 1985 and 1986.

4.4 Impact Factors of Salinity Intrusion in the Mekong Delta and Several Impact Assessment Studies

Although saltwater intrusion is a natural phenomenon and affected by topographic, climatic, and hydrologic conditions, human activities may change these conditions, especially topography and hydrology. The river channels may be deepened and widened for navigation and transportation projects. Hydroelectric, irrigation, and water diversion projects may change the hydrologic conditions including flows and duration. These activities tend to exaggerate saltwater intrusion and may have adverse potential impacts.

Conceivable impact factors that significantly influence salinity intrusion in the Mekong Delta are given as follows:

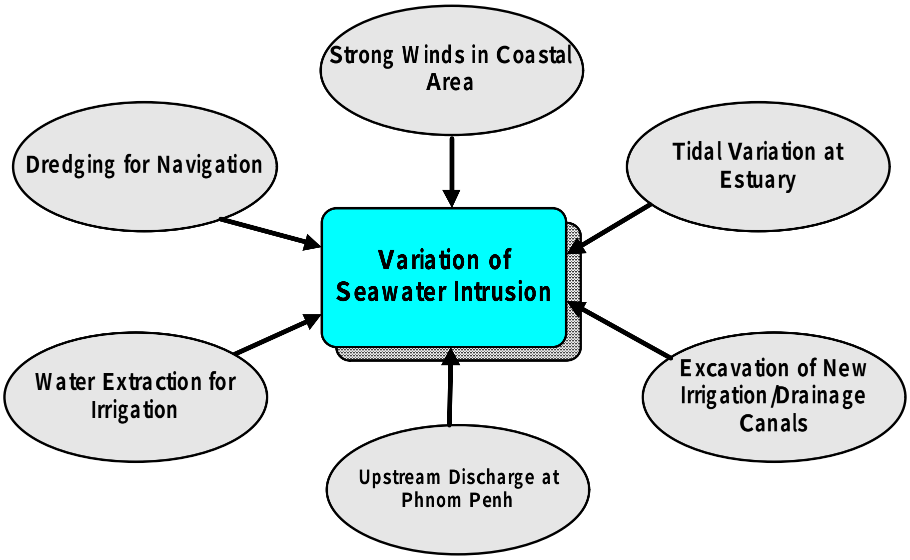


Fig. 4.16 Impact Factors of Seawater Intrusion in the Mekong Delta

There have been several studies undertaken in the framework of Salinity Intrusion Studies in the Mekong Delta in relation to the impact assessment due to the external factors given above. Significant study results regarding the impacts are discussed in the next subsections.

4.4.1 Dredging for Navigation

In the Mekong Delta, navigation plays an important role in economic activities and development. Besides small boats going into canals, large ships come into the main rivers in the delta. At the moment, ships of some thousands tons may easily pass the Cua Tieu branch of the Mekong River and the Dinh An branch of the Bassac River. In this connection, navigation for such large ships requires channels that are carefully investigated and dredged, in particular, at the river mouth.

At the time of the study for reference undertaken in 1992, the river mouth of Dinh An branch had been dredged 3 times since 1975, i.e., once in each year of 1981, 1983 and 1991. All dredging activities were made in the dry season in March-June. It has been reported that as a result of dredging the maximum salinity in each year has changed with an increasing trend as shown in the following table.

Table 4.14 Maximum Monthly Salinity at Dai Ngai in the Bassac River

(Unit: g/l)

Year	Month					
	Jan	Feb	Mar	Apr	May	Jun
1978	2.8	4.7	7.2	7.2	-	-
1979	1.5	1.6	2.3	5.9	3.5	2.4
1983	1.8	3.6	3.3	3.6	4.8	9.1
1984	0.6	-	1.2	1.5	1.1	0.5
1986	0.1	0.4	8.2	4.2	8.0	0.4
1989	4.9	5.5	9.2	5.7	5.5	5.0
1990	2.5	3.1	4.2	7.0	7.9	1.5
1991	0.2	0.9	3.8	5.9	12.0	0.9

Source: Effects on Configuration Changes on Flow Distribution and Salt Water Intrusion, Program of Salinity Intrusion Studies in The Mekong Delta Phase III, SIWRPM, 1992

The maximum salinity of 9.1 g/l and 12.0 g/l were observed in June 1983 and in May 1991. It was estimated that the sudden increment of salinity was due to the increase of well-mixed conditions and the higher intrusion caused by dredging. The dredging work was carried out along the selected channel of 80-100 m wide and 4-5 m deep below the lowest low water, i.e., at elevation of minus 7 m to minus 8 m. However, it was considered that because the dredged volume was rather small, only 1-5% of the total cross-sectional area might have been dredged.

The salinity measured upstream at An Lak Tay did not show an abnormal salinity increase in May 1991. Due to this comparison, it was concluded that the increase of salinity was only a local phenomenon at the locations of rather high salinity, although the guided conclusion deems somewhat not based logical thinking. It was expected that a usual salinity variation would occur in the succeeding year.

4.4.2 Withdrawal of Irrigation Water

The irrigation development activities usually require excavation and dredging of canals. The table below shows the change of maximum salinity due to irrigation development in the West Vam Co River.

Table 4.15 Maximum Monthly Salinity at Tan An in the West Vam Co River in the Mekong Delta

(Unit: g/l)

Year	Month					Jun
	Feb	Mar	Apr	May	Jun	
1978	8.1	11.4	14.2	12.3	5.1	
1979	2.3	11.7	15.1	12.2	5.1	Before dredging
1987	-	4.0	9.2	7.0	2.7	
1988	-	4.0	9.5	6.8	2.7	Small irrigation area
1990	5.6	9.1	13.0	13.0	5.4	Large irrigation area

Source: Effects on Configuration Changes on Flow Distribution and Salt Water Intrusion, Program of Salinity Intrusion Studies in The Mekong Delta Phase III, SIWRPM, 1992

As seen above, the salinity in the West Vam Co River was reduced after the dredging of canals, then increased after the increase of irrigation water extraction at Tan An.

Other study results are available in relation to the effects on salinity intrusion due to fresh water intake from the Mekong River. The Netherlands Delta Development Team carried out the study in 1974. Under the study salinity distribution curves were approximated for all the branches of the Mekong except for the Cua Dai, based on the monthly averages of results of measurements at the banks during the years 1935 through 1942 and on the conductivity measurements during the year 1973. In terms of the shift of salinity distribution curves in upstream direction when discharge in a river branch will decrease at arbitrary amounts, the expected decrease of salinity intrusion was preliminarily analysed under the condition that the lowest dry season discharge is 2,000 m^3/s at Phnom Penh. The results are summarised below.

Table 4.16 Shift of Salinity Curves due to Decrease of Fresh Water in the Mekong Delta

(Unit: km)

River	Decrease of Fresh Water in Branch		
	100 m^3/s	200 m^3/s	300 m^3/s
Cua Tieu	Discharge becomes negative	Discharge becomes negative	Complete salinization
Cua Dai	10	Discharge becomes negative	Complete salinization
Ham Luong	10	Discharge becomes negative	Complete salinization
Co Chien	1.5	3.5	5
Dinh Hann	1	2.5	4
Bassac	1	2	3

Note: Shift is under the condition of lowest discharge (Qp=2,000 m3/s)
Source: Recommendations Concerning Agricultural Development with Improved Water Control in the Mekong Delta, 1974

Salinity intrusion impacts are different for each year, depending on not only hydro-meteorological conditions, but also on the consumption of water of the main river that is likely to cause the decrease of flow to make deeper salinity intrusion. The increase of water use in the dry season also translates to lower flow that coincides with increase of salinity intrusion impact. This might be a conflict between development and protection of water resources.

4.4.3 Tide and Strong Wind in Coastal Area

Tide is the main factor affecting the variation of water levels in the estuaries and the salinity intrusion in the delta. There is a cycle in the variation of water level. Under the Programme of Salinity Intrusion Studies, this cycle was determined and analyzed for about 15 days.

There is a relationship between the variation of water level and the monsoons. The East wind has a cycle of around 15 days and is usually strong in February-March. It is one of the main factors causing the rise of sea water level from February to April and the highest salinity at the seaward boundary in March. There is a close relation between the strong wind and the rising of sea water level. The rising of sea water level resulting from strong wind causes an impoundment of fresh water and a great impact on the salinity intrusion in the delta estuaries. The regression between the wind and the rising of water level is therefore one of technical factors for the existing salinity forecasting in the delta.

4.4.4 Potential Impacts on the Mekong Delta

Quang M. Nguyen summarizes the potential impacts on the Mekong Delta in his paper “Overview of Saltwater Intrusion in the Mekong Delta” in 1999. Saltwater is intruding into the Mekong River because the river flows have been reduced, especially during the dry season. Low flows may be caused by prolonged droughts and/or water resources projects for irrigation, water supply, and inter-basin diversion including irrigation projects using the Mekong River flow within the Delta. The Mekong River and the interconnected canal system are the primary sources of water supply for domestic use and irrigation in the Delta. Therefore, direct potential impacts of saltwater intrusion on the Mekong Delta would be a loss of that water supply source. A large area along the Mekong River and canal system may not be cultivated because of a lack of freshwater. Agricultural production in areas of high chloride concentrations may be decreased. In areas with very high chloride concentrations, crops and fruit trees may be destroyed and fishery production may be severely affected. More importantly, these potential impacts may spread into larger areas in the delta connected to affected reaches by man-made canals. When reaching these inland areas, saltwater would be difficult to be flushed out and its potential impacts may last for a long time. In the long-term, saltwater intrusion may become an obstacle for the development of the entire Mekong Delta. In addition to the direct potential impacts, saltwater intrusion may have other potential impacts, especially on the environment. In the areas of saltwater intrusion, the ecosystem of the Mekong River and Mekong Delta may be disturbed and unbalanced. These potential impacts may not be recognized until significant changes in the ecosystem occur. The reduction in the Mekong River flows may be caused by prolonged droughts and/or water resources projects in the Mekong River basin, including the projects in the Mekong Delta; therefore, saltwater intrusion in the Mekong River is truly a basin-wide problem. To solve this problem properly and adequately, a basin-wide solution is required. This solution does not appear to be simple and easy because of unique natural conditions of the Mekong River and the Mekong Delta, and of conflicts of interest among riparian countries within the Mekong River basin. For those reasons, an appropriate and long-term solution for the saltwater intrusion problem in the Mekong River would not be realized without an international cooperation on the basis of equity, openness, freedom, and respect of mutual benefits of all riparian countries.

4.5 Water Quality in the Mekong Delta

Water quality monitoring results in both the Mekong and Bassac rivers in Vietnam and Cambodia are presented in Tables 4.17 to 4.20. Key features of the Mekong River water quality are summarized below.

(1) In general, the Mekong River water has shown any of chemical pollution and is good for many purposes. Although water resources in the Mekong Delta are very abundant, the geological structure, topography characteristics, and human activities have caused impacts on water quality, restricting utilization of these resources. Main constraints consist of acidic water, salinity intrusion, and other impacts from human activities.

(2) There is a possibility of water pollution in both the Mekong and Bassac Rivers. It means that the water quality becomes worse as it flows to downstream by the return flows from agricultural lands and municipal wastewater of urban areas within the Delta. Dissolved nutrient and phosphorous concentrations will lead to eutrophication in the both Rivers which may lead to deteriorating water quality. If the Mekong Delta is developed more rapidly, the water quality becomes worse due to human activities such as farming, urbanization and industrialization.

(3) The water quality of the upstream and middle part of the Delta near Phnom Penh and the Vietnam-Cambodia border is very good except the high TSS due to high turbidity during the wet season.