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Interactive comment on "The role of glaciers in stream flow from the Nepal Himalaya" *by* D. Alford and R. Armstrong

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I wish to thank Mr. Shea for his review of our paper. I also wish to stress once again that the paper he reviewed is, as stated in the text, a summary of a more-detailed report describing methodologies and findings from a study of the glaciers and rivers of Nepal, undertaken for the World Bank. This summary was only intended to present the more-salient findings, and a very general description of the methodologies employed. This study was conducted at a time when the topic of glaciers and rivers in the mountains of Asia had been highly politicized by individuals with an apparent agenda, but little actual understanding of either the glaciers or rivers of the Himalaya. While the IPCC has conceded the error of "2035", there seem to be residual misconceptions from the rather unfortunate era of glaciers as icons of anthropogenic climate change

that remain in the present conventional wisdom. Our paper is an attempt to deal with one of those apparent misconceptions (below)* - the importance of the glaciers of the eastern Himalaya in the volume of flow in the Ganges River.

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* an extract from the original report:

"It is not possible to conduct an assessment of the role of glaciers in the Nepal Himalaya without becoming aware of the major role played by discussions of the impacts of climate change on glaciers and glacier-fed streamflow in both the technical and lay literature for at least the past decade. There is general agreement among earth scientists that a widespread retreat of the global ice cover has been occurring since at least the early 1800s. In recent years, evidence has been presented (IPCC, 2007) in support of the hypothesis that a major change in historical patterns of the global climate may be occurring. It has been suggested that glacier retreat is linked to climate change, as a result of anthropogenic causes related to the increase of CO2 and other "greenhouse" gases in the atmosphere. However, an understanding of the significance of glacier retreat in terms of changes in glacier mass balance or the resulting water resource availability is extremely limited, and has generated a number of conflicting responses. Much of the debate over the significance of the IPCC findings has been conducted in the context of political, rather than scientific, concerns. This may be particularly true of mountain hydrometeorology and glaciology. The IPCC results contain few data from high mountain sites. To compensate for this lack, many have pointed to the general retreat of mountain glaciers as indicators of current climate trends at all mountain locations. Some opinions have verged on the apocalyptic. The following is from the World Wildlife Fund paper, "An Overview of Glaciers, Glacier Retreat, and Subsequent Impacts in Nepal, India and China" (2005, p.2):

"The New Scientist magazine carried the article "Flooded Out – Retreating glaciers spell disaster for valley communities" in their 5 June 1999 issue. It quoted Professor

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Syed Hasnain, then Chairman of the International Commission for Snow and Ice's (ICSI) Working Group on Himalayan Glaciology, who said most of the glaciers in the Himalayan region "will vanish within 40 years as a result of global warming". The article also predicted that freshwater flow in rivers across South Asia will "eventually diminish, resulting in widespread water shortages".

The Intergovernmental Panel on Climate Change (IPCC, Working Group II, Fourth Assessment Report 2007) cited the 2005 World Wildlife Fund paper as a source in stating: "The current trends of glacial melt suggest that the Ganga, Indus, Brahmaputra and other rivers that criss-cross the northern Indian plain could likely become seasonal rivers in the near future as a consequence of climate change and could likely affect the economies in the region".

Variations on this theme have been taken up by the popular press:

"There's a growing consensus, however, that one of the most severe effects will be on the glaciers of the Himalayas. Their meltwater currently supplies up to 85% of the flow of the Ganga, Brahmaputra and Indus rivers. Latest IPCC estimates suggest that they may shrink to one-fifth of their volume within a few decades. Initially this will cause floods as the waters melt – and then a water crisis of unprecedented proportions as the rivers dry" (Slavin and Mehra, 2008), with similar, if less extreme, forecasts in technical publications:

"Under the uniform warming scenario of +0.06°C per year, impacts of declining glacier area on river flow will be greater in small, more highly glaciated basins in both the western and eastern Himalayas. Flow for the most glaciated sub-catchments (glaciations $\geq$ 50%) will attain peaks of 150 and 170% of initial flow around 2050 and2070 in the west and east respectively before declining until the respective glaciers disappear in 2086 and 2109".(Rees and Collins 2006, quoted in Xu, et.al, 2007).

Bennett, et.al, writing in Nature in 2005, stated that, ". . ..the hydrological cycle of the region is complicated by the Asian Monsoon, but there is little doubt that that melting

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glaciers provide a key source of water for the region in the summer months, as much as 70% of the Ganges river and 50-60% of the flow in other major rivers" (Bennett, et.al, 2005). The authors provide no data to support this assertion.

It is probable that the movie, "An Inconvenient Truth" in which retreating and calving glaciers are used as an icon of "global warming", and for which Albert Gore and the Intergovernmental Panel on Climate Change (IPCC) received the Nobel Prize, was a factor in increasing the concerns that are expressed over the potential impact of glacier retreat.

Recently, the World Glacier Monitoring Service, WGMS, University of Zurich, Switzerland, circulated the following by e-mail: ... "The statement of Himalayan glaciers...disappearing with very high likelihood by the year 2035 as well as the one about the Himalayan glacier area...likely shrink from present 500,000 to 100,000 km2 by the year 2035, as made in Chapter 10.6 (Case studies) of the IPCC report of the Working Group II (2007), is under present state-of-knowledge, not plausible. The sources given do not support the statement (Table 10.9, IPCC 2007) and are a non-reviewed report of an organisation without expertise in glaciology (WWF 2005). As a consequence this statement should not have been published in the IPCC report (2007). Future scientific studies are to pick up such statements and to provide a sound answer to it, which is to be summarized in the next IPCC report" (Michael Zemp, WGMS, michael.zemp@geo.uzh.ch, 2008)".

The entire report is now in press, and I am reluctant to rewrite it for these discussions, just to demonstrate that we did cross most of our t's, and dot most of our i's. If desired by the editors of Cryosphere Discussions, I will be happy to contact the World Bank to determine if they would object to the entire 90 page report being placed into the Discussions.

There seems to be an unfortunate tendency in some academic circles to feel that the

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list of references is more important than the findings and conclusions. In the case of Mr. Shea's review, there seems to be some concern that our findings and conclusions may be based mostly on a lack of understanding of the literature. For Mr. Shea, as well as all other potential readers in academia who may be interested, I include below a list of most of the materials we consulted while involved in the study. There are some we undoubtedly overlooked, and there were some we deemed irrelevant, repetitious, or in error. In general, however, I suspect most who have worked in the Nepal Himalaya will find themselves represented. One person overlooked in the literature review was Prof. V. Klemes, and I would like to recommend his papers to Mr. Shea, and any others who might be interest in mountain hydrology, the role of scale, and hydrological modeling. They are easy to find on Google Scholar.

In an invocation of the literature, one wants to make certain that most relevant materials are considered. I feel Mr Shea's use of the literature is somewhat selective. As an example, he refers to the letter by Cogley, et.al, 2010, in Science, but overlooks the note by Pallava Bagli in a earlier issue of the same journal (11/13/2009), as well as the report by the Indian glaciologist Raina, that played a role in inspiring the response by Cogley, et.al.

In passing - an earlier version of this summary was included in a paper prepared by Prof. Jack Ives as one in a lengthy series of papers and books he has written debunking Himalayan myths. While we ultimately requested that the paper not be submitted for publication, it is my understanding from Prof. Ives that it was reviewed by Prof. Cogley, and received generally good marks.

The following list of references represents a majority, but not all, of the materials that have been read in developing an understanding of the relationship between glaciers and streamflow in the Nepal Himalaya. Not all of these references appear in the text of this report, but are included here primarily to show the broad scope of the problem, of studies pertaining to aspects of the problem, and the widely scattered nature, and character of data and opinions on the subjects pertaining to this relationship.

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1. Ageta, Y, Ohata, T, Tanaka, Y, Ikegami, K, Higuchi, K, (1980) Mass and Heat Balances of the Glacier AX010, Shorong Himal during the Summer Monsoon Season, East Nepal'. In Seppyo, Journal of the Japanese Society of Snow and Ice, 41: 34–41 (special issue)

2. Ageta, Y., and Higuchi, K., 1984, Estimation of mass balance components of a summer-accumulation type glacier in the Nepal Himalaya, Geografiska Annaler, Series A, Physical Geography, V.66, N. 3, pp. 249-255.

3. Alford, D., 1986, Mountain hydrologic systems, Jour. Mountain Research and Development, V. 5, N. 4, pp. 349-363.

4. Alford, D., 1988, Water Resources Management in the Hindu Kush-Himalayan Region, Environment And Policy Institute, East West Center, Honolulu, Hawaii, 89 pp.

5. Alford, D., 1992. Hydrological aspects of the Himalayan region. ICIMOD Occasional Paper No. 18, Kathmandu, Nepal, 68 pp.

6. Andrews, J., Fahey, B., and Alford, D,. 1971, Note on correlation coefficients derived from cumulative distributions with reference to glaciological studies, Jour. of Glaciology, Vol. 10, No. 56, pp. 145-147.

7. Asahi, K., Watanabe, T., 2000, Past and recent glacier fluctuation in Kanchenjunga Himal, Nepal. Journal of Nepal Geological Society, 22: pp 481-490

8. Bagchi, A., 1982, Orographic variation of precipitation in a high-rise Himalayan basin, Hydrological Aspects of Alpine and High Mountain Areas, Proceedings of the Exeter Symposium, July, 1982, IAHS Pub. 138.

9. Bahr. D, Meier, M, and Peckham, S., 1997, The physical basis of glacier volume-area scaling, Jour. Geophysical Research, , Vol. 102, No. B9.

10. Barry, R.,. 1990. Change in mountain climate and glacio-hydrological responses, Mountain Research and Development, 10 pp 161-170.

11. Barry, R., and Chorley, R., 1970, Atmosphere, Weather and Climate, Holt, Rinehart and Winston, Inc., New York, p.

12. Benn, D.,and Gemmell, A. (1997) Calculating equilibrium-line altitudes of former glaciers by the balance ratio method: a new computer spreadsheet Glacial Geology and Geomorphology, http://ggg.qub.ac.uk/ggg

13. Benn, D. I.and Owen, L. A. (1998). The role of the Indian summer monsoon and the mid-latitude westerlies in Himalayan glaciation: review and speculative discussion. Journal of the Geological Society 155(2), 353-363.

14. Bennett, T., Adams, J., and Lettenmaier, D., 2005, Potential impacts of a warming climate on water availability in snow-dominated regions, Nature, V. 438/17, November 2005.

15. Berthier, E., Arnaud, Y., Kumar, R., Ahmad, S., Wagnon, P. and Chevallier, P. (2007). Remote sensing estimates of glacier mass balances in the Himachal Pradesh (Western Himalaya, India). Remote Sensing of Environment 108(3), 327 - 338.

16. Bruijneel, L., and Bremer, C., 1989, Highland-Lowland Interactions in the Ganges Brahmaputra River Basin: A Review of Published Literature, ICIMOD Occasional Paper No. 11, Kathmandu, Nepal, 135 pp.

17. Chaohai, Liu; Liangfu, Ding (1986) 'The Newly Progress of Glacier Inventory in Tianshan Mountains'. In Journal of Glaciology and Geocryology, 8(2): 168–169

19. CGIAR-CSI. (2004). Void-filled seamless SRTM data V1. International Centre for Tropical Agriculture (CIAT), available from the CGIAR-CSI SRTM 90m Database: http://srtm.csi.cgiar.org and http://www.ambiotek.com/topoview

20. Cool, J., 1983, Factors Affecting Pressures on Mountain Resource Systems, Mountain Development Opportunities and Challenges, Proceedings of the First International symposium and Inauguration of the International Centre for Integrated Mountain Developmennt, Kathmandu, p.28

21. DHM, 1988, Hydrological Records of Nepal, Streamflow Summary, Updated Version, Department of Hydrology and Meteorology, His Majesty's Government of Nepal, Ministry of Water Resources, Kathmandu.

22. DIHM, 1977, Climatological Records of Nepal, 1921-1975, Special Supplement, Kathmandu Valley, V. II, Dep't of Irrigation, Hydrology and Meteorology, Kathmandu.

23. DIHM, 1977, Dep't of Irrigation, Hydrology and Meteorology, Climatological Records of Nepal, Vol. 2,.

24. Dreyer, N., Nikolayeva, G., and Tsigelnaya, I., 1982, Maps of streamflow resources of some high mountain areas in Asia and north America, Hydrological Aspects of Alpine and High Mountain Areas, Proceedings of the Exeter Symposium, July, 1982, IAHS Pub. 138.

25. Dyurgerov, M.B and Meier, M.F., 1997. Mass balance of mountain and sub-polar glaciers: A new global assessment for 1961-1990, Arctic and Alpine Research, 29(4), pp. 379-391. 64

26. Dyurgerov, M. B., Meier, M. F, 2000. Twentieth century climate change: Evidence from small glaciers. Proceedings of the National Academy of Sciences, 97 (4): 1406-1411.

27. Fujita, K., Takeuchi, N., and Seko, K., 1998, Glaciological observations of Yala Glacier in the Langtang Valley, Nepal Himalayas, 1994 and 1996, Bull. Glacier Research, 16, pp. 75-81.

28. Geiger, R., 1966, The Climate Near the Ground, Harvard University Press, Cambridge, Massachusetts, 611 pp.

29. Geological Survey of India, 1999. Inventory of the Himalayan Glaciers: A Contribution to the International Hydrological Programme, Special Publication No. 34, edited by M.K. Kaul.

30. Hagen, T., 1980, Nepal: The Kingdom in the Himalayas, Oxford and IBH Publishing, New Delhi, 264 pp.

31. Haeberli, W and Hoelzle, M., 2001. The World Glacier Monitoring Service. (http://www.nercbas ac.uk/public/icd/icsi/WGMS.html)

32. Haeberli, W., 1990. Glacier and permafrost signals of 20th century warming. Annals of Glaciology, 14, p 99-101

33. Haefli, R., 1962, The ablation gradient and the retreat of a glacier tongue, International Association of Hydrological Sciences Pub. 58, pp. 49-59.

34. Holeman, J., 1968, The sediment yield of major rivers of the world, Water Resources Research, 4: 737-747

35. Higuchi, K., Ageta, Y., Yasunari, T., and Inoue, J., 1982, Characteristics of the precipitation during the monsoon in high-mountain areas of the Nepal Himalaya, HydrologicalAspects of Alpine and High Mountain Areas, Proceedings of the Exeter Symposium, July, 1982, IAHS Pub. 138.

36. ICIMOD and UNEP 2000. Inventory of glaciers, glacial lakes and glacial lake outburst floods, monitoring and early warning system in the Hindu Kush Himalayan Region, Bhutan.

37. ICIMOD, 1996, Climatic and Hydrological Atlas of Nepal, International Centre for Integrated Mountain Development, Mountain Natural Resources Division, Suresh R. Chalise, Director.

38. IYM 2002, Bishkek Mountain Platform, 2002, Bishkek Global Mountain Summit, United Nations, Bishkek, Kirghystan. Sec 6.3. Actions at the National Level.

40. Hock, R., 2003, Temperature index melt modeling in mountain areas, Jour. Hydrology, V. 282, pp. 104-115.

41. IPCC, 2007, Intergovernmental Panel on Climate Change, Chapter 10.6 (Case

studies) of the IPCC report of the Working Group II.

42. Kadota, T., Seko, K. and Ageta, Y. 1993. Shrinkage of glacier AX010 since 1978, Shorong Himal, east Nepal. In: Young, G.J. (ed.) Snow and Glacier Hydrology (Proc. Kathmandu Symp. Nov. 1992) IAHS Publ. No. 218,145-154.

43. Kadota, T., Fijita, K., Seko, K., Kayastha, R. B., and Ageta, Y. (1997). Monitoring and prediction of shrinkage of a small glacier in Nepal Himalaya. Annals of Glaciology 24, 90-94.

44. Kadota, T., Seko, K., Aoki, T., Iwata, S., and Yamaguchi, S. (2000). Shrinkage of Khumbu Glacier, east Nepal from 1978 to 1995. IAHS Publication No. 264 264, 235-243.

45. Kaser, G., and Osmaston, H., 2002, Tropical Glaciers, Cambridge University Press, 207 pp.

46. Kaser, G., 2001, Glacier-Climate interaction at low-latitudes, Jour. Glaciology, 2001.

47. Kattelmann, R., 1993, Role off snowmelt in generating streamflow during spring in east Nepal, IAHS Publ. 218,

48. Kattelmann, R., 1987, Uncertainty in Assessing Himalayan Water Resources, Mountain Research and Development, Vol. 7, No. 3, Proceedings of the Mohonk Mountain Conference: The Himalaya-Ganges Problem, (Aug., 1987), pp. 279-286

49. Konz, M., Braun, L., Grabs, W., Shrestra, A., and Uhlenbrook, S., 2006, Runoff from Nepalese Headwater Catchments – Measurements and Modeling, Deutsches Nationalkomiteefur das International Hydrological Programme (IHP) der UNESCO und das Hydrology und Water Resources Programme (HWRP) der WMO, Koblenz, 2005.160 pp.

50. Kulkarni, A. V. (1992). Mass Balance of Himalayan Glaciers Using AAR and ELA

Methods. Journal of Glaciology 38(128), 101-104.

51. Kulkarni, K., Bahuguna, I., Rathore, B., S ingh, S., Randhawa, S., Sood, R., and Dhar, S., 2007, Glacier retreat in Himalaya using Indian remote sensing satellite data, Current Science, V. 92, N. 1, 10 January, 2007.

52. Leung, L., Wigmosta, S., Ghau, D., Epstein, D., and Vail, L., 1996, Application of a subgrid orographic precipitation/land surface hydrology scheme to a mountain watershed, J. Geophys. Res., 101, D8, 12, 803-812,

53. Macheret, Y. Y., P. A. Cherkasov, and L. I. Bobrova, Tolschinai ob'em lednikov Djungarskogo Alatau po danniy aeroradiozondirovaniyaM, ater. GlyatsiologicheskikhIssled. Khronika Obsuzhdeniya, 62, 59-71, 1988.

54. Mayewski P., and P. A., Jaschke (1979): Himalaya and Trans Himalayan glacier fluctuation since A. D., 1812. Arctic and Alpine Research 11(3), pp 267-287.

55. Mayewski, P., Pregent, G., Jeschke, and P., Ahmad, N., 1980, Himalayan and Trans-Himalayan glacier fluctuations and the south Asian monsoon record, Arctic and alpine research, V. 12, N. 2, pp. 171-182.

56. Meier, M., 1961, Mass budget of South Cascade Glacier, 1957-60, U.S. Geol. Survey Prof. Paper 242-B, pp. 206-211.

57. Meier, M., and Post, A., 1962, Recent variations in mass net budgets of glaciers in western North America IASH Publication, 1962

58. Miller, D., (1981) Water at the Surface of the Earth: An Introduction to Ecosystem Hydrodynamics, International Geophysical Series, Vol. 21, Academic Press, New York, 557 pp.

59. Mool, P.K.; Wangda, D., Bajracharya, S.R.; Kunzang, K.; Gurung, D.R. and Joshi, S.P. (2001). Inventory of Glaciers, Glacial Lakes and Glacial Lake Outburst Floods, ICIMOD, Kathmandu, Nepal.

60. Naito, N., Nakawo, M., Kadota, T. and Raymaond, C.F. (2000). Numerical Simulation of Recent Shrinkage of Khumbu Glacier, Nepal Himalayas, International Association of Hydrological Sciences Publication 264 (Symposium at Seattle 2000 - Debris Covered Glaciers), pp.245-264.

61. Mote, P., and Kaser, G., 2006, The shrinking glaciers of Kilimanjaro: Can global warming be blamed?, American Scientist, V. 95, July-August 2006, pp.318-325.

62. Nakawo, M., Fujita, K., Ageta, Y., Shankar, K., Pokhrel, A.P. and Tandong, Y. (1997). Basic Studies for Assessing the Impacts of the Global Warming on the Himalayan Cryosphere, 1994-96, Bull. Glacier Res., Vol. 15: 53-58.

63. Ohmura, A. (2001). Physical Basis for the Temperature-Based Melt-Index Method. Journal of Applied Meteorology 753-761.

64. Osmastton, H., 2005, Estimates of glacier equilibrium line altitudes by the Area×Altitude, the Area×Altitude Balance Ratio and the Area×Altitude Balance Index methods and their validation Quaternary International Volumes 138-139, September-October 2005, Pages 22-31

65. 65.Pelto, M., 1988, The annual balance of North Cascde glaciers,Wasington, USA, measured and predicted using an activity-index method, Jour. Glaciology, Vol. 34, No. 117, pp.194-199.

66. Rabus, B., Eineder, M., Roth, A. and Bamler, R. (2003). The shuttle radar topography mission–a new class of digital elevation models acquired by spaceborne radar. ISPRS Journal of Photogrammetry and Remote Sensing 57(4), 241-262.

67. Rana, B. N., M., Fukushima, Y. and Ageta, Y. (1997). Application of a conceptual precipitation-runoff model (HYCY-MODEL) in a debris-covered glacierized basin in the Langtang Valley, Nepal Himalaya. Annals of Glaciology 25(226 - 231).

68. Raina, V., 2009, Himalayan Glaciers: A State-of-the-art Review of Glacier Studies, Glacier Retreat and Climate Change, Ministry of Environment & Forests Government

of India, G.B. Pant Institute of Himalayan Environment & Development, Kosi-Katarmal, Almora, India.

69. Rasmussen, L., and Tangborn, W., 1976, Hydrology of the North Cascade Range, Washington: 1. Runoff, Precipitation and storage characteristics, Water Resources Research, 12(2), pp. 187-202.

70. Rao, K., 1984, River basins of India, Resource Geography, Heritage Publishers New Delhi, IndiaRasmussen, L., and Tangborn, W., 1976, Hydrology of the North Cascades region, Washington:2. a proposed hydrometeorological streamflow prediction model, Water Resources Research, V. 12, N. 2, pp. 203-216.

71. Rees, G., and Collins, D., 2004, SAGARMATHA: Snow and Glacier Aspects of Water Resources Management in the Himalayas (sic), DFID Project No. R7980, An assessment of the potential impacts of deglaciation on the water resources of the Himalaya, Centre for Ecology and Hydrology, Crowmarsh Gifford, Wallingford, Oxfordshire UK, OX10 8BB.

72. Rees, G., and Collins, D., 2006, Regional differences in response of flow in glacier-fed Himalayan rivers to climatic warming, Hydrological Processes, 20, Wiley Interscience, pp. 2157-2169.

73. Rees, G, Holmes, M., Young, A., Kansakar, S., 2004a, Recession-based hydrological models for estimating low flows in ungaged catchments in the Himalayas, Hydrology and Earth Systems Sciences, V. 8, N. 5, pp. 891-902

74. Rees, G., Sullivan, C., and O'Regan, D., 2004b, SAGARMATHA. Snow and glacier aspects of water resources management in the Himalaya, Final Technical Report, V. 1, Project Overview, Centre for Ecology and Hydrology, Crowmarsh Gifford, Wallingford, Oxfordshire UK, OX10 8BB.

75. Ren, D., and Karoly, D., 2007, Predicting the response of seven Asian glaciers to future climate scenarios using a simple linear glacier model, Jour. Geophys. Res. V.

113.

76. Ren, D., Karoly, D., Leslie, L., 2006, Temperate mountain-glacier melting rates for the period 2001-30: Estimate from three coupled GCM simulations for the greater Himalayas, Jour. Applied Meteorology and Climatology, V. 46, No.6 pp. 890-899.

77. Riggs, H., and Hanson, R., 1969, Seasonal low-flow forecasting, Hydrological Forecasting, Tech. Note N. 92, World Meteorological Organization, N. 228, TP. 122, pp. 286-299.

78. Sharma, C., 1977, River Systems of Nepal, Navana Printing Works Private Ltd.,47 Ganrsh Chander Street, Kathmandu, 214 pp.

79. Sharma, C., 1983, Water and energy Resources of the Himalayan Block, Navana Printing Works Private Ltd., 47 Ganesh Chander street, \Kathmandu, 477 pp.

80. Shrestha, A. B., Wake, C. P., Mayewski, P. A., and Dibb, J. E. (1999). Maximum temperature trends in the Himalaya and its vicinity: An analysis based on temperature records from Nepal for the period 1971-94. Journal of Climate 12, 2775-2787.

81. Shrestha, A. B., Wake, C. P., Mayewski, P. A., and Dibb, J. E. (2000). Precipitation fluctuations in the Himalaya and its vicinity: An analysis based on temperature records from Nepal, . International Journal of Climate 20, 317-327.

82. Singh, P., Kumar, N., and Arora, M., 2000, Degree-day factors for snow and ice for Dokriani Glacier, Garwhal Himalaya, Jour. Hydrology, V. 235, pp. 1-11.

83. Slavin, T., and Mehra, M., 2008, Under the Weather in India, Chinadialogue, February 21, 2008, London, England.

84. Thayyen, R., and Gergan, J., 2009. Role of glaciers in watershed hydrology: “Himalayan catchment” perspective, The Cryosphere Discussions 3, 443–476, Copernicus Publications on behalf of the European Geosciences Union.

85. Thompson, M., and Warburton, M., 1985, Uncertainty on a Himalayan Scale, Jour.

86. Thompson, M., and Warburton, M., 1986, Decision-making in the face of contradictory certainties: How to save the Himalayas when you can't find out what's wrong with them, Jour. Applied Systems Analysis, 1986.

87. Tangborn, W.and Rana, B. (2000). Mass balance and runoff of the partially debris-covered Langtang Glacier, Nepal. In: Nakawo, M., Raymond, C. F. & Fountain, A. (eds), Debris-covered glaciers, Vol. 264, IAHS, Wallingsford. 53 - 61

88. Tangborn, W., 1999, A Mass Balance Model that Uses Low-altitude Meteorological Observations and the Area-Altitude Distribution of a Glacier, Geografiska Annaler, Series A: Physical Geography 81 (4).

89. Tangborn, W., 1984, Prediction of glacier-derived runoff for hydroelectric development, Geogr Ann. 66A(3), pp. 257-265.

90. Tangborn, W., and Rasmussen, L., 1976, Hydrology of the North Cascades region, Washington: 2. a proposed hydrometeorological streamflow prediction model, Water Resources Research, V. 12, N. 2, pp. 203-216.

91. Tangborn, W., and Rasmussen, L., 1977, Application of a hydrometeorological model to the south-central Sierra Nevada of California, Jour. Research, U.S. Geol. Survey, V. 5, N. 1, Jan-Feb 1977, pp. 33-48.

92. Tetsuzo, Y., and Jiro, I., 1976, Characteristics of monsoonal precipitation around peaks and ridges in Shorong and Khumbu Himal, Seppyo, Journal ofthe Japanese Society of Snow and Ice, pp. 26-31

93. Thornthwaite, C., 1953, Topoclimatology, Symposium on Microclimatology and Micrpmeteorology, Toronto Meteorological conference" Toronto, Ontario, Canada, September 15, 1953

94. Todd, D., 1959, Groundwater Hydrology, Second Edition, John Wiley and Sons,

New York, 533 pp.

95. UNEP, 2002, United Nations Environmental Programme, Mountain Watch: Environmental Change and Sustainable Development in Mountains, UNEP World Conservation Monitoring Centre, Cambridge, UK.

96. UNESCO, 1971, Discharge of selected rivers of the world, No. 5, V. 1, p. 32, 48, V.2, pp. 97-101, V. 3, pp. 57-59.

97. Wagnon, P., Rajesh Kumar, Yves Arnaud, Anurag Linda, Parmanand Sharma, Christian Vincent Jose Pottakal Etien Berthier, Alaqppan Ramanathan, Syed Iqbal Hassnain and Pierre Chevalier. (2007). Four years of mass balance on Chhota Shigri Glacier, Himachal Pradesh, India, a new benchmark glacier in the western Himalaya. Journal of Glaciology 53(183), 603 - 611.

98. Ward. R., 1975, Principles of Hydrology, 2nd Ed., McGraw-Hill Co. Ltd., London, England.

99. Watanabe, O., 1980, On the types of glaciers in the Nepal Himalaya, and their characteristics, in: Glaciers and Climates of the Nepal Himalayas, Report of the Glaciological Expedition to Nepal, SEPPYO, Jour. Of the Japanese Society of Snow and Ice, V. 41, Special Issue.

100. WGMS - World Glacier Monitoring Service, 1998, Into the Second Century of Worldwide Glacier Monitoring – Prospects and Strategies. (Eds. Haeberli, W., Hoelzle, M. and Suter, S.). UNESCO Studies and reports in hydrology No. 56. Interactive comment on The Cryosphere Discuss., 4, 469, 2010.

101. World Wildlife Fund Nepal, 2005, An Overview of Glaciers, Glacier Retreat and subsequent Impacts in Nepal, India and China, WWF Nepal Program, Kathmandu, Nepal, 70 pp.

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