LIGHT POLLUTION HANDBOOK

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LIGHT POLLUTION HANDBOOK

by

KOHEI NARISADA

and

DUCO SCHREUDER

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to Tsuyako and Fanny

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The CIE Colour Triangle

*Colour descriptions
according to the
Munsell Colour
Scheme*

*Example of a
training field for
soccer football*

*Active road markings
with LEDs in road studs*

*Road lighting with
CIE cut-off lanterns*

Outdoor lighting of Shirakawago village, Japan. A World Cultural Asset

Decorative lighting for the historical port of Moji, Japan

*Illumination for Akashi-Kaiko bridge, Japan.
With 3911 m the longest suspension bridge in the world*

Preface

This book deals with light pollution and about the ways to reduce it. Light pollution is one of the negative side-effects of artificial outdoor lighting. The term light pollution is an unhappy one, but as no better alternative seems to exist, it will be used throughout this book.

The function of all outdoor lighting is to enhance the visibility or the aesthetics in the nighttime environment. The light should come where it is needed. If not, it is spilled, causing economic and environmental losses as well as disturbance and discomfort. The overall effects are termed 'light pollution'; a major form of light pollution is the glow extending over the night sky.

Sky glow is discussed in many astronomical textbooks and in many popular brochures. The present book is primarily aimed at those responsible for outdoor lighting installations. Thus, an engineering approach has been chosen. The level of the book is that of 'college' or 'University level'. The book is organized in two parts. The first seven chapters cover the areas of general interest, and conclude with recommendations. The second part deals with the scientific and engineering elaboration of the first part. A number of examples are included that refer to specific outdoor lighting installations and projects that are directly related to the reduction of light pollution. Finally, some information is given about the authors.

(a) About light pollution

This book deals with light pollution. It is understood that light pollution is one of the negative side-effects of outdoor lighting. As is explained in several chapters of this book, outdoor lighting is essential for our type of society to survive. The side-effects are real. It is one of the objectives of this book, to show that they can be reduced by technical and organizational methods, so that the disturbance caused by light pollution can be lessened.

A point that must be made clear right from the beginning, is the use of the term 'light pollution'. To begin with, the term is actually a mishap, probably originating from the similarity in words with 'air pollution' and 'water pollution'. In these cases, it is the air or the water that gets dirty. Light cannot, in the same way, get dirty. As is explained in several chapters of this book, light is not only beneficial, but it is essential for all life on Earth. As mentioned already, there are negative side-effects. Whether the side-effects

must be regarded as ‘pollution’, however, depends on the concepts of nature, the environment and of the ‘human condition’ that are favoured.

(b) About the book

This book deals with light pollution in a very general sense. Its nature of a ‘handbook’ implies that most effects of light pollution will be discussed. Some details are not discussed; they will be indicated later in this section. The emphasis is on those aspects of light pollution that interfere with astronomical observations. As will be explained later-on, astronomers are a major victim-group of light pollution.

As is explained earlier, light pollution is one of the negative side-effects of artificial outdoor lighting. The outset is that all outdoor lighting is functional, its function being the enhancement of the visibility or of the aesthetics in the night-time environment. Light pollution represents a loss as regards electric energy. Good lighting design ensures that the light comes where it is needed, and does not fall elsewhere. If not, the light is ‘spilled’. It may cause considerable economic and environmental losses. Furthermore, spill light from outdoor lighting installations often causes disturbance and discomfort for those that have nothing to do with the lighting. The light invades into the private sphere of people. This is ‘intrusive light’ or ‘light trespass’. The overall effects are termed ‘light pollution’, with the proviso made in the foregoing part of this section.

One of the most conspicuous forms of light pollution is the ‘sky glow’ that extends over all near and distant sources of light pollution. Sky glow is the result of light that is projected upwards, and then scattered back to the surface of the Earth. Part of the light that is emitted by the light sources is directed straight up. Another contribution to the sky glow results from light that, after having been ‘used’, has been reflected upwards.

Sky glow is discussed in detail in a number of excellent textbooks that are listed in sec. 15.2a. These textbooks are almost exclusively written by and for experts, in most cases professional or advanced amateur astronomers. They are, however, hardly useful for the general public, for policy makers, and for the authorities that are responsible to uphold the quality of life. Apart from these textbooks, one can encounter a wide variety of articles, brochures and pamphlets that describe in great detail the adverse effects of sky glow and of light pollution in general. Several of these publications are listed in the following sections of this book.

The present book tries to fill the gap that exists between the astronomical textbooks and the popular brochures. It is aimed at all people directly involved – full time or part time – in outdoor lighting, people that come in contact with light pollution. It gives details of the different aspects that are relevant in dealing with the problems related to light pollution, its cause, and its reduction. The main audience of the handbook is the authorities that are responsible for the design, installation and maintenance of outdoor lighting installations, with a special reference to the reduction of light pollution effects. It is also aimed at the managers of astronomical observatories and at the authorities and decision makers

responsible for the organization and maintenance of the public space. Also, it will serve a good purpose in education, particularly in graduate or postgraduate curricula for scientists, engineers, economists, and law students.

Thus, an engineering approach has been chosen, implying that the book aims at practical and economically feasible solutions for problems that are stated in scientific terms. The main characteristic of the engineering approach is that an optimum solution is looked for – often an attempt to reach a compromise between what different aspects would ideally require. As will be clear in several sections of this book, subjective elements may play some role in reaching the optimum. In this way, the engineering approach differs from the approach that aims at maximization – an approach that is often used in studies related to the natural sciences. Both the engineering approach and the natural-sciences approach are, however, based on scientifically valid data.

The level of the book corresponds to this audience. The level might be characterised as ‘college level’ – or University level for European audiences. Details that are time-sensitive or controversial are not put on the foreground, to ensure that the book is not out of date too soon and that it remains readable for readers of different outlooks. This does not mean that it is strictly objective; the personal opinions and preferences of the authors may be gleaned when looking closely at the text.

The book is to a large extent based on the investigations that have been made by the authors themselves. This means that there is an emphasis on the results of studies that were made in Japan and in the Netherlands respectively. This preference is supported by the fact that in the area of outdoor lighting, Japan and the Netherlands have always made large contributions. One of the reasons for this is that these countries are the home of several of the most important lighting industries in the world. It goes without saying that in many respects the contribution of other countries is just as important. When conceiving the book, great care is made to present the material in a fashion that guarantee a world-wide use for the book.

The different aspects of light pollution and of sky glow are dealt with in different degrees of detail, so as the subject requests. Mathematical arguments are restricted to a minimum. As far as feasible, reference is made to more detailed studies. Also, the wide subject of light scatter in the atmosphere is not dealt with. Neither are the technical details of outdoor lighting design, nor the details of legislation and regulation. These subjects are very relevant, but it was felt that they are too specialized for a more general readership. Neither are cost aspects dealt with in detail. This refers to the costs of light pollution and the costs of the implementation of light pollution countermeasures. The reason is three-fold. First, the costs of light pollution are only in part of a monetary nature. Second, costs estimates vary very much in time. Precise indications would make the handbook obsolete in a short time. And third, probably the most important, cost aspects vary very much between different areas in the world. So is energy, including electric energy, much cheaper in the US than in almost all other countries of the world. When the costs are compared to the

GNP of a country, the differences are much larger. As an example, we might compare the USA with Tanzania, one of the poorest countries in the world. In the USA, the per capita GPN is US\$ 24 750, in Tanzania US\$ 90 (1993 data). With a price of electric energy per MWh of 5 and 10 US\$ respectively, the US citizen has to work 0,323 hours for one MWh, whereas the Tanzanian must work 89 hours for that – well over two weeks. Because there is so little ground for an easily comparison, cost considerations are dealt with only in summary in this handbook. A comprehensive bibliography is included at the end of each chapter of the book. This approach is reflected in the structure of the book.

As regards optical astronomy, light pollution is not its only disturbance. Important sources of man-made interference with astronomical observations are passing aircraft, contrails (the vapour trails left by passing aircraft), satellites and space debris. Furthermore, vibrations and dust – e.g. from nearby mining activities – may have adverse effects. In earthquake-sensitive areas, geophysical disturbances may pose serious difficulties. These disturbances are not dealt with in this book. For obvious reasons, radio astronomy and the many disturbances like interference by radio and television broadcasts by electromagnetic disturbances in general, are not dealt with either. We will, however, give some references that may serve the interested reader. To begin with, it did almost become a tradition that conferences on interference of astronomical observations discuss as the three main items: light pollution, radio interference, and space debris. The proceedings of such conferences give a considerable amount of further information. See for these aspects Cohen & Sullivan, eds. (2001); Crawford, ed. (1991); Isobe & Hirayama, eds. (1998); Kovalevsky, ed. (1992); McNally, ed. (1994); Schwarz, ed. (2003).

Passing aircraft and contrails are discussed in some detail in Pedersen (2001). The lights of the aircrafts themselves may damage CCD receivers (Kovalevsky, 1992, sec. 6.5), whereas the heat from the aircraft exhaust may reduce the ‘seeing’ (Pedersen, 2001, p. 174). After the passage of the aircraft, condensation trails (‘contrails’) may form that interfere with astronomical observation. Contrails are understood to increase the overall cloudiness world-wide by 0,1% and in Europe by 0,5%. In general, they do not seem to be a serious threat for astronomical observations, but it seems that under special meteorological circumstances, their influence is much bigger (Anon., 2002). It is estimated that in most parts of Western Europe, more than 1 to 2% of the noon-time sky is covered by ‘young’ persistent contrails, whereas the larger part of continental USA is covered for over 2% (Pedersen, 2001, figure 1, based on data from Mannstein et al., 1999). It is therefore recommended to select sites for observatories far away from air routes (Pedersen, 2001, p. 177).

Geophysical disturbances have been discussed in some detail in Anon. (1984). See also Barlier & Kovalevsky (1992). The matter is very topical in view of the fact that some of the major observatories in the world, like e.g. Cerro Paranal in Chile and Mauna Kea in Hawaii, are built on more or less active volcanoes, where the region is by nature earthquake-sensitive.

(c) *The organization of the book*

The book is organized in two main parts. The first part covers the areas of general interest. It includes a general discussion of the problems of light pollution and a survey of the remedial measures. It also gives recommendations. It is aimed at all people directly involved – full time or part time – in light pollution, the main audience being the authorities and decision makers responsible for the organization and maintenance of the public space. This part ends with recommendations that are aimed at minimizing the negative aspects of light pollution.

The second part, from Chapter 8 onwards, deals with the scientific and engineering elaboration of the material covered in broad lines in the first part. There is some overlap between the two parts. The second part is aimed at professional scientists and engineers, such as the managers of astronomical observatories, the designers of lighting equipment, and the installateurs of lighting installations. Mathematical arguments are restricted to a minimum. Both first and second part may serve for graduate or postgraduate curricula for scientists, engineers, economists, and law students.

Two points must be clarified. The first regards the language of the book. The authors did all they reasonably could do to ensure that the meaning is made clear to the reader; although they tried to do this in UK-English, it should be realised that some Japanese-English and Dutch-English crept in, in spite of the efforts of Mr Stephen Harris, who checked the language. The authors wish to apologize if this leads to some obscurity.

The second point refers to the problem of the decimal sign. The authors used the ISO-standard for writing numbers, which means that the ‘comma’ is used for the decimal sign and a space between powers of one thousand. This agrees to the international ISO Standard ISO 31-0:1992 ‘Quantities and units – Part 0: General principles’. In section 3.3.2 of that standard, it is stated: “The decimal sign is a comma on the line. If the magnitude of the number is less than unity, the decimal sign should be preceded by a zero” (ISO, 1992, p. 11). This ISO-standard is followed by the great majority of scientific organizations and standardizing organizations worldwide, more in particular by CIE and CEN. In view of the fact that this book is aimed at a world-wide readership, and also to help to promote the use of international standards, this system was adopted in this book, in spite of the fact that IAU and some countries like UK and USA do otherwise.

(d) *About the authors*

Kohei NARISADA was born on 28 November 1929 in Kyoto. He obtained his degree in electrical engineering at Doshisha University, Kyoto, Japan. On joining Matsushita Electric in 1953, he was involved in lighting design at the Lighting Division. In 1962, he transferred to the newly established Lighting Research Laboratory and was involved in investigations concerning road and tunnel lighting. Between 1976 and 1989, he was head of the Lighting Research Laboratory. In 1976, he obtained a doctor degree (Engineering) at Kyoto University on tunnel entrance lighting. Between 1987 and 1991 he was the president of Japanese National Committee of CIE. After his retirement from

the company in 1989, he became a professor of the Psychology Department at Chukyo University, Nagoya, Japan and was teaching visual perception in relation to road lighting. In 2003, he retired from the University. He is the honorary member of the Illuminating Engineering Institute of Japan, and a Chartered Engineer of CIBSE, UK. He became involved in international activities of Technical Committees of CIE on road and tunnel lighting in 1967. Since then, he is the member of a number of CIE technical committees on road and tunnel lighting, the chairman of the sub-committee on tunnel lighting. He is also a member of CIE technical committee dealing with the countermeasures for light pollution. Since 1979, he served a term as a member of the CIE Action Committee; he has been the Director of Division 7 and between 1991 and 1999 he was a Vice President of CIE. He is the co-author of several books and a great many scientific and technical papers.

Duco Anton SCHREUDER was born 1931 in Rotterdam, the Netherlands. In 1949 he graduated from the classical secondary school in Breda. After his national service from 1952 to 1954 as an officer in the Meteorological Service of the Dutch Royal Air Force, he took a masters degree in applied physics from the Delft University in 1958. In 1964, he was awarded a Doctorate of Technology from the Eindhoven University. In 1972 he took a masters degree in philosophy (specialization psychology) at the Haarlem International Institute. From 1958 to 1968 he was a research scientist at the Lighting Laboratories of Philips in Eindhoven. From 1968 to 1993 he was a Senior Researcher with SWOV Institute for Road Safety Research in Leidschendam. Since 1993 he is an independent consultant in the general fields of lighting and safety. Dr Schreuder is the author and co-author of several books and well over 300 scientific publications. He was and is the Chairman or member of a large number of national and international institutions and working groups, particularly in the Commission Internationale de l'Eclairage CIE, in the Comité Européen de Normalisation CEN, and in the Organization for Economic Cooperation and Development OECD.

The authors first met in the early 1960's, when their work on tunnel lighting lead in a natural way to an exchange of ideas and later to close cooperation. This cooperation was extended to most areas of outdoor lighting, focussing the last decade on matters of light pollution and of the interference by light of astronomical observation. The present book is a fruit of this decade-long cooperation of the two authors.

(e) Abbreviations

In this book, a number of abbreviations are used. Most of them are listed here, although many are explained in the text where they show up. The translations given here are indicative only. Most are not authorised; they are given only for matters of information.

ALCoR	Astronomical Light Control Region
Anon	'Anonymous', Author not known, or not indicated
ASP	Astronomical Society of the Pacific, San Francisco, USA
AVV	Adviesdienst Verkeer en Vervoer, Rijkswaterstaat (Transport Research Centre, Ministry of Transport, Public Works and Water Management). Rotterdam, the Netherlands
BAA	British Astronomical Association, London, UK
CBS	Centraal Bureau voor de Statistiek (Central Statistical Bureau). The Hague, the Netherlands
CCD	Charge-coupled Device
CEN	Comité Européen de Normalisation. Brussels, Belgium
CIBSE	Chartered Institute of Building Services Engineers. London, UK
CIE	Commission Internationale de l'Eclairage. Paris, France; now Vienna, Austria
COSPAR	Committee on Space Research
CROW	Centrum voor Regelgeving en Onderzoek in de Grond-, Water- en Wegenbouw en de Verkeerstechniek (Centre for regulation and research in soil, water and road engineering and traffic engineering). Ede, the Netherlands
DIN	Deutsches Institut für Normung e.V. (German Standards Institution)
DMSP	Defense Meteorological Satellite Program
DSC	Duco Schreuder Consultancies. Leidschendam, the Netherlands
DWW	Dienst Weg- en Waterbouw, Ministerie van Verkeer en Waterstaat (Department of road and waterway construction, Ministry of Transport, Public Works and Water Management), Delft, the Netherlands
EC	European Commission. Brussels, Belgium
EN	European Norm
GCRI	General Colour Rendering Index
HID-lamp	High Intensity Discharge lamp
IAU	International Astronomical Union. Paris, France
ICSU	Council for Science – formerly International Council of Scientific Unions
IDA	International Dark-Sky Association. Tucson, Arizona, USA
IDN	International Dark Sky Association Holland. Utrecht, The Netherlands
IEC	International Electrotechnical Commission
IES	The Illuminating Engineering Society of North America. New York, USA
IEIJ	Illuminating Engineering Institute of Japan. Tokyo, Japan
ILE	The Institution of Lighting Engineers. Rugby, UK
IPCC	Intergovernmental Panel on Climate Change
IRF	International Road Federation. Geneva, Switzerland
ISO	International Standards Organization
IUCN	International Union for Conservation of Nature and Natural Resources
IZF/TNO	Instituut voor Zintuigphysiologie TNO (Institute for Perception TNO). Soesterberg, the Netherlands (now TM/TNO)
JCIE	Japanese National Committee of CIE
LITG	Lichttechnische Gesellschaft (Association for illuminating engineering). Berlin, Germany
LNV	Ministerie van Landbouw, Natuurbeheer en Visserij (Ministry of Agriculture, Nature Policy and Fishery) Den Haag, the Netherlands
NSVV	Nederlandse Stichting voor Verlichtingskunde (Illuminating Engineering Society of The Netherlands). Arnhem, the Netherlands
NOVEM	Nederlandse Maatschappij voor Energie en Milieu bv (Society for energy and the environment of the Netherlands). Sittard, The Netherlands
OECD	Organization for Economic Cooperation and Development. Paris, France
OLS	Optical Linescan System

PAOVV	Orgaan voor postacademisch onderwijs in de vervoerswetenschappen en de verkeerskunde. (Organisation for post-graduate studies in transportation sciences and traffic engineering). Rijswijk/Delft, the Netherlands
PrEN	European Pre-Norm
RHT	retinohypothalamic nerve tract
SANCI	South African National Committee on Illumination
SCOPE	Scientific Committee on the Problems of the Environment
SCOSTEP	Scientific Committee on Solar Terrestrial Environment Problems
SCRI	Special Colour Rendering Index R_i for an individual colour
SCW	Studiecentrum Wegenbouw (Study Centre for Road Construction SCW). Arnhem, the Netherlands (now CROW)
SCN	suprachiasmic nucleus
SVT	Stichting Studiecentrum Verkeerstechniek (Study Centre for Traffic Engineering) Driebergen, the Netherlands (now CROW)
SWOV	Stichting Wetenschappelijk Onderzoek Verkeersveiligheid (Institute for Road Safety Research). Leidschendam, the Netherlands
TRB	Transportation Research Board. Washington, DC, USA
TRRL	Transport and Road Research Laboratory. Crowthorne, Berks., UK (now TRL)
UNESCO	United Nations Educational, Scientific and Cultural Organization
V&W	Ministerie van Verkeer en Waterstaat (Ministry of Transport, Public Works and Water Management). Den Haag, the Netherlands
VNM	Vereniging Natuurmonumenten – formerly Vereniging tot Behoud van Natuurmonumenten (the Society for the Preservation of Nature Monuments). 's Graveland, The Netherlands
VROM	Ministerie van Volkshuisvesting, Ruimtelijke Ordening en Milieubeheer (Ministry of Public Housing, Land Planology and Environmental Policy). Den Haag, the Netherlands
WHO	World Health Organization. Geneva, Switzerland
WVC	Ministerie van Welzijn, Volksgezondheid en Cultuur (Ministry of Well-being, Public Health and Culture)
WWF	World Wildlife Fund

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